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# ELECTRIC TRACTION
## FOR RAILWAY TRAINS

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# ELECTRIC TRACTION

## FOR RAILWAY TRAINS

A BOOK FOR STUDENTS, ELECTRICAL AND MECHANICAL ENGINEERS, SUPERINTENDENTS OF MOTIVE POWER AND OTHERS INTERESTED IN THE DEVELOPMENT OF ELECTRIC TRACTION FOR RAILWAY TRAIN SERVICE.

BY

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TO

FREDERICK S. JONES

DEAN OF YALE COLLEGE

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IN RECOGNITION OF THE AUTHOR'S INDEBTEDNESS

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# PREFACE.

A development in electric traction for railway trains is in progress the extent of which is scarcely realized except by those engaged in electric railway engineering.

The work of electrification now completed by four large steam railroads, the New York Central, the New York, New Haven & Hartford, the Long Island, and the Pennsylvania, at their New York terminals, and by the Great Northern Railway and the Spokane and Inland Empire Railroad in the state of Washington, presents notable examples of this application of electric motive power. It has led other important railway companies in this country to consider the advantages of electric power, both for old steam roads and for all new railways.

The opportunity which has been given railroads to utilize the advantages of electric motive power has already resulted in a remarkable growth. No more striking display of progress in electrical engineering can be obtained than that shown in the illustrations of the various types of electric transportation equipment built since 1906. Equipment has been strengthened commensurate with the needs; details of design and control have been perfected; manufacture, maintenance, and inspection have been simplified, until the motive power of electric trains now presents no serious difficulties in modern railroad operation.

No publication relating particularly to the subject of electric traction for railway trains has appeared in America, because the men who were qualified by experience and knowledge to write have not found time, or have been prevented by business reasons. In the writer's opinion such a work is needed, and this book has been published in the hope that it may meet this need. It is not, however, intended as a popular treatise upon the subject, for it is assumed that the reader has a good knowledge of steam and electric railway practice.

The substance of the work was delivered in 24 lectures on electric railway transportation, in 1908–9–10–11, to the senior students in electrical engineering at the University of Minnesota.

The material has been systematically collected since the year 1900, which marked the close of seven years' service as electrical engineer for the Twin City Rapid Transit Company, operating the electric railways and long interurban lines in and near Minneapolis and St. Paul. This was followed by much valuable experience on steam locomotive tests and on

dynamometer cars, and later in electrification plans for several steam roads. Electrification work throughout the country has been inspected and studied for use in consulting practice, the data thus collected being used as a basis for the material contained in the book. Viewpoints have been obtained from many sides and angles. Ideas of steam railroad officials, of superintendents of motive power, of steam and electric locomotive enginemen, of manufacturers, and of skeptical bankers have been weighed and sifted. Facts, comparisons, descriptions, statistical tables, leading opinions, results in operation, and references to the best current literature have been collected to constitute a book of reference for engineers. Manifestly all of the material and tables could not be presented, but special effort has been made to avoid passing judgment or stating conclusions without presenting the important issues and sometimes the details of the case.

In the use of the work as a text-book, emphasis should be given to a study of statistical tables to bring out conclusions, when, in consideration of the present status of electric railway transportation, it is possible to do so. Classification in itself is not valuable and stress should be laid on the function of the relations of the elements involved. The limitations on practical electrification must be observed to get good foundations for a study of economic problems and efficient methods of train operation. Technical reports by students on the relative merits of mechanical connections, electric systems, train equipment, on methods of development, and on economies of train operation will bring out good results if they are criticised, revised, and discussed pro and con, by the students themselves.

The book is further intended as a guide for those who desire to follow the development and practical application of electric traction on American trunk-line railroads. The history and present status are carefully outlined to give a preliminary survey; and in general the subjects are treated from the view point of steam railroad men who desire to study electric motive power. Data on cars, trucks, power station design, substation practice, manufacturer's data, wiring diagrams, etc., are not presented. Electric traction for street railways is not considered, and details of interurban railways which do not run cars in trains are omitted. The subject has been limited, as the title indicates, to Electric Traction for Railway Trains.

MINNEAPOLIS,
*September*, 1911.

EDWARD P. BURCH.

## ACKNOWLEDGMENTS.

First-hand information has been received from a host of railroad men, from consulting engineers, and from managers of properties; and their courtesies are appreciated, as otherwise parts of the statistical tables and operating data, ordinarily kept "behind a stone wall," could not have been reviewed. The writer is indebted to the leading steam and electric railway papers, the Railway Age Gazette and the Electric Railway Journal, for reliable, up-to-date information, and especially for the stimulus received from their able and comprehensive editorials.

## DEFINITIONS.

There are four terms, frequently used herein, to be explained:

**Railways** refer to all kinds of roads where vehicles are moved on metallic rails by steam or electric motors.

**Railroads** refer particularly to those railways which have 4 feet $8\frac{1}{2}$ inches track gage; a private right-of-way and private terminals; freight and passenger traffic, with cars in trains; and the Master Car Builders' standards, for interchange of equipment with other railroads.

**Tons** refer to weights of 2000 pounds; not to British or metric tons, of 2240 or 2204 pounds.

**Mileage** refers to single-track miles, not route miles.

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# ELECTRIC TRACTION FOR RAILWAY TRAINS

## CHAPTER I.

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### INTRODUCTION.

The history of electric traction for railway-train service is studied in order to understand the progress which has been made during the past twenty years in transportation methods, and to understand the service conditions surrounding the application of electric power. This study gives a proper view point for a perspective, it gages the value of present endeavor, and it outlines the magnitude of some of the problems which are now before railway companies.

The history of transportation shows clearly that improvements in motive power and methods are attained only by slow development and careful experiment; also that railway service demands economy of power, ample capacity, reasonable designs, flexibility, and interchangeable equipment; for without these things the best results are not obtained, and investments are not most productive.

The history of railway electrical engineering may state the sequence and nature of the development, but it should also review both the

mistakes and the triumphs of the past; and when the elements in the advancement of transportation are so presented, they form an inducement to present thought and endeavor.

In a study of railway electrical engineering it is well to acquire specific information on approved modern engineering methods, and a good knowledge of the technology of railways. A study should develop the relations of separated features, and bring out the economic principles underlying all transportation work.

## FIRST ELECTIC RAILWAYS.

The years 1830 to 1860 mark the first period of experiment in the application of electrical energy for transportation. The work of experimenters was limited to the application of permanent magnets and reciprocating motion, and by the lack of serviceability and capacity from chemical batteries.

About 1835, Thomas Davenport, of Brandon, Vermont, made over 100 models of electric railway motor cars, which he operated by batteries. One patent specified "the production of rotary motion by repeated changes of magnet poles," and the use of a commutator. Third-rail conductors and track-return circuits were used. Elec. World, Oct. 6, 1910.

In 1842, Davidson built a 7-ton, 2-axle car for the Edinburgh-Glasgow Railway. Each axle carried a wooden cylinder on which were fastened three bars of iron, parallel to the axle. Four electromagnets were arranged in pairs on each side of each cylinder. Current was produced by an iron-zinc sulphuric acid battery. The electromagnets attracted the bars on the cylinder, then alternately the current was cut off and on, and rotation was produced. A speed of four miles per hour was obtained. Aspinwall, to Institution of Mechanical Engineers, 1910.

In 1847, Lilley and Cotton, of Pittsburg, and also Moses G. Farmer, of Dover, N. H., operated small cars in which, with electricity from a battery, alternate attraction and repulsion of magnets produced motion.

In 1851, Thomas Hall, of Boston, exhibited an electric motor car at the Mechanics' Fair. An electro-magnetic armature revolved between the poles of a permanent magnet.

In 1851, C. G. Page, of Washington, D. C., employed a 100-cell nitric-acid battery. His car received motion from two solenoids, or hollow magnets, which alternately attracted cores on a plunger. This reciprocating motion was transmitted to the wheels by means of a crank. A speed of 19 m. p. h. was attained, yet very few improvements were made, and the car was dubbed the "electro-magnetic humbug."

Between 1860 and 1866, **dynamos or electric generators** were being

developed; yet it was some time before it was discovered that an electric generator could drive a similar machine, now called a motor.

In 1867, Moses G. Farmer operated a car with a motor and dynamo.

In 1879, Siemens and Halske, at the Berlin Industrial Exhibition, propelled a miniature locomotive and three cars, with electric power from a dynamo. The track rails, 1000 feet long, formed a 160-volt circuit. Spur and bevel gears were used to transmit the power from a 3-h.p. motor. This demonstration was repeated at Brussels and Dusseldorf, also at Frankfort, in 1881. See photograph in St. Ry. Journ., Oct. 8, 1904, p. 536.

In 1880, Thomas A. Edison at Menlo Park, New Jersey, ran a small locomotive, using power from a dynamo. See section on electric locomotives in this chapter.

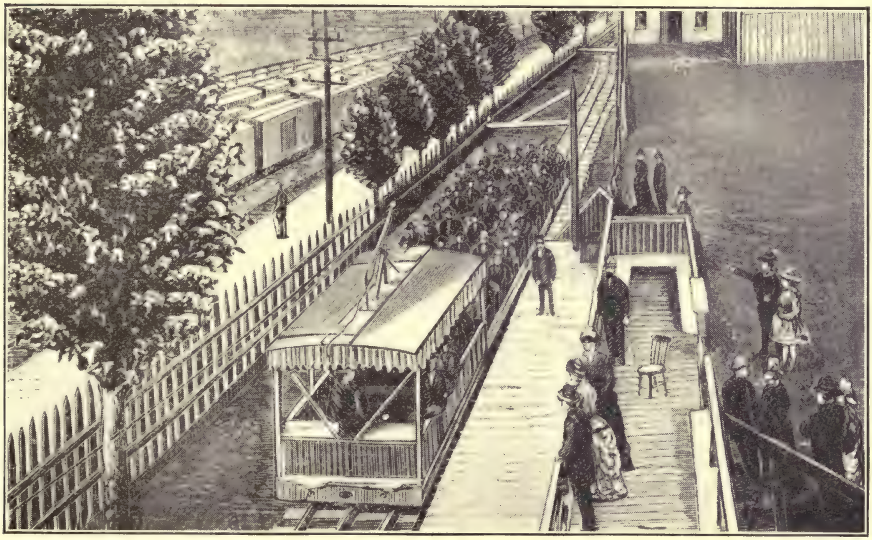

FIG. 1.—ELECTRIC MOTOR CAR AND TRAIN. VAN DEPOELE, TORONTO, 1884.

In 1881, Stephen D. Field ran a large motor car at Stockbridge, Massachusetts, using a dynamo, a positive wire enclosed in a conduit, and a track-rail return.

In 1881, Siemens operated cars at the Paris Exposition with current from an overhead slotted tube in which a contact shoe slid, and power was transmitted by the motor to the axle thru a chain; and, in 1885, at the Vienna Exposition, a 150-volt Siemens dynamo supplied current thru two insulated rails to a motor in a car.

In 1883, Van Depoele built experimental and exhibition lines at Chicago, and used an overhead trolley wire, an over-running trolley wheel,

held in position by ballast, the trolley wheel being connected to the car by means of a flexible cable.

In 1884, Van Depoele ran an electric railway train at the Toronto Exposition, using a 1000-volt contact line in an underground conduit, 3000 feet long; and again in 1885, on a one-mile road. Van Depoele used an under-running trolley, and patented the scheme.

In 1884, Daft built an electric railway on one of the piers at Coney Island; and used the track rails for the two conductors. This was repeated at expositions in Boston and in New Orleans.

**First Public Electric Cars for City Streets (1880-1888).**—In 1881, Siemens and Halske constructed a short commercial road, at Lichterfelde, near Berlin. Two insulated track rails were used in a 180-volt circuit.


Fig. 2.—Daft Electric Motor Car, Baltimore, 1884.

The wheel tire was insulated from the hub by a wooden band. Later an overhead trolley line, with a rolling contact at the wire, was used. See photograph in St. Ry. Journ., Oct. 8, 1904, p. 535. The road is now running as a 600-volt trolley line.

In 1883, Siemens cars were operated in Paris, London, and elsewhere, by storage batteries with 5-h.p., 100-volt motors.

In 1883, Siemens and Halske constructed a third-rail, narrow-gage line, 6 miles long, the Portrush Railway near the Giants' Causeway, in northern Ireland, obtaining from a water-fall the power for operating a 250-volt, direct-current dynamo.

In 1884, E. M. Bentley and Walter H. Knight operated in Cleveland, Ohio, a road having two miles of underground conduit, placed between the rails. This installation was perhaps the first in which the cars were

driven by a series motor, placed under the car floor. Wire-rope and sprocket-chain drive, and later, bevel gearing, were tried. The road was operated about one year. See Martin and Wetzler's "The Electric Motor," 1887; St. Ry. Journ., Feb., 1889; Bentley, Elec. World, March 5, 1904.

In 1884, Daft operated a pioneer line, 2 miles long, for the Union Passenger Railway Co., between Baltimore and Hampden. Two 3-ton motor cars were used to haul trailers. The over-running trolley and a third-rail contact were both installed. The motors were a series, 130-volt, direct-current, single-geared type. Elec. World, March 5, 1904.

In 1885, John C. Henry built an electric railroad in Kansas City.

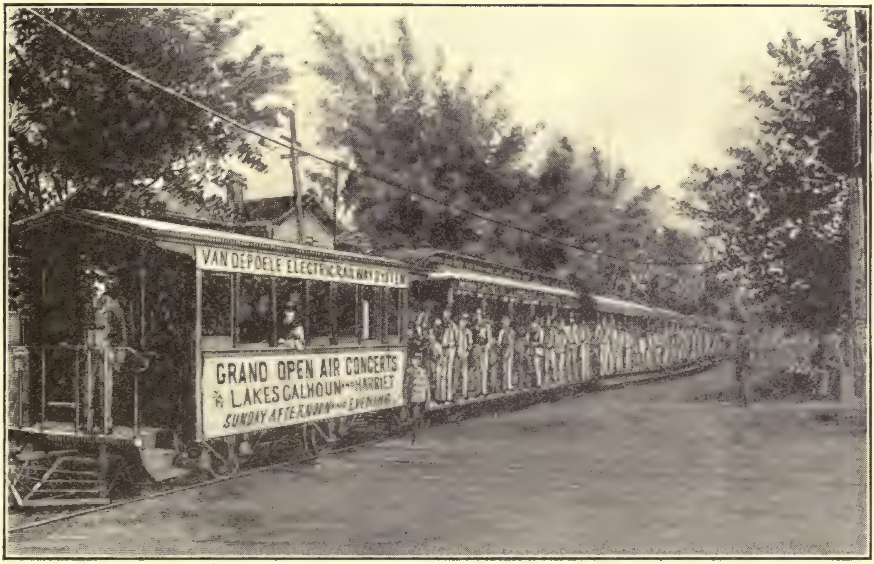


FIG. 3.—ELECTRIC LOCOMOTIVE CAR AND TRAIN. VAN DEPOELE, MINNEAPOLIS, 1886.

There were two cars, each equipped with a 7-h.p., 250-volt, direct-current motor. The overhead trolley wires were 10 inches apart, and two pairs of over-running trolley wheels were held by springs in lateral contact with each wire, the trolley wheels being mounted on a single carriage, and connected with the motors by means of flexible cables. The creditors received 8 cents on a dollar. Elec. World, Oct. 20, 1910, p. 934.

In 1886, Van Depoele, working at Minneapolis for the Minneapolis, Lyndale and Minnetonka Railway, which had been obliged to discontinue the use of steam locomotives in the business portions of the city, equipped an electric locomotive car for hauling trains.


FIG. 4.—STANDARD STREET CAR AND MOTIVE POWER, 1870–1890.

FIG. 5.—DAFT ELECTRIC MOTOR CAR. MANSFIELD, OHIO, 1887.

A Weston bipolar, 20-h.p. motor, with spocket-chain drive to an axle, was located above the floor line of a 4-wheeled open car. Current was taken from an overhead copper wire by means of an over-running, ballasted trolley, which was attached to the car body by flexible cables. A 12x18 slide-valve engine, belted to an electric generator, furnished energy, which was transmitted from 2 to 3 miles. Four 10-ton open excursion coaches, having a loaded weight with passengers of about 60 tons, were hauled on the level, but two were a load for the curves and grades. The trial line was 1.5 miles long, and contained one long 3.5 per cent. grade and two sharp curves. Mr. Thomas J. Janney, superintendent of the road, recently stated to the writer that, while the equipment was crude, it had many of the elements for success. The president of the road decided that the overhead construction at curves and the serious arcing at the rail joints could not be remedied. The heavy maintenance expense and lack of capacity in the electric motor caused it to be condemned, and it was abandoned for a soda motor. St. Ry. Journ., Oct. 8, 1904, p. 560.

**A summary on public street railways to 1888** shows that cars were generally propelled by horses or mules. Animal power was expensive to operate, depreciation was rapid, service was slow, and sufficient drawbar pull and speed were not available. Experiments without number had been tried with steam engines, electric motors, gas, hot-air, and chemical motors, as the motive power for local railway transportation. Electric street railways were simply an experiment.

EARLY ELECTRIC STREET RAILWAYS IN AMERICA.[1]

| Year | Month. | Engineer. | Miles. | Cars. | Motors. | Location of road. |
|---|---|---|---|---|---|---|
| 1884 | July | Bentley and Knight. | 2.0 | 3 | 1–14 h.p. | Cleveland, O. |
| 1885 | Aug. | Leo Daft........... | 2.0 | 3 | 1–8 | Baltimore, Md. |
| 1885 | ....... | John C. Henry...... | .... | 2 | 1–7 | Kansas City, Mo. |
| 1885 | ....... | John C. Henry...... | .... | 1 | ........ | Orange, N. J. |
| 1885 | Oct. | C. J. Van Depoele.. | 1.0 | 4<br>1 | 1–5<br>1–10 | South Bend, Ind. |
| 1885 | Oct. | C. J. Van Depoele.. | 1.0 | 3 | 1– | Toronto, Ont. |
| 1885 | Oct. | S. H. Short......... | 0.5 | 1 | 1–8 | Denver, Colo. |
| 1886 | Jan. | C. J. Van Depoele.. | 1.5 | 1 | 1–20 | Minneapolis, Minn. |
| 1886 | June | C. J. Van Depoele.. | 1.2 | 2 | 1–20 | Windsor, Ont. |
| 1886 | July | C. J. Van Depoele.. | 5.0 | 5 | 1–10 | Appleton, Wis. |
| 1886 | Sept. | C. J. Van Depoele.. | 2.7 | 4 | 1–15 | Port Huron, Mich. |
| 1886 | Sept. | C. J. Van Depoele.. | 1.0 | 1 | ........ | Detroit, Mich. |
| 1886 | Oct. | F. E. Fisher........ | 3.7 | 4 | 1–10 | Detroit, Mich. |
| 1886 | Nov. | C. J. Van Depoele.. | 5.0 | 9<br>3 | 1–15<br>2–12 | Scranton, Pa. |
| 1886 | Nov. | C. J. Van Depoele .. | .... | 12 | ........ | Montgomery, Ala. |
| 1886 | Dec. | Leo Daft........... | 1.0 | 1 | ........ | Orange, N. J. |

[1] See references on early electric railways at end of this chapter.

EARLY ELECTRIC STREET RAILWAYS IN AMERICA.—*Continued.*

| Year. | Month. | Engineer. | Miles. | Cars. | Motors. | Location of road. |
|---|---|---|---|---|---|---|
| 1887 | July | C. J. Van Depoele.. | 4.0 | 8 | 1–15 | Lima, Ohio. |
| 1887 | Aug. | Leo Daft........... | 4.0 | 6 | ........ | Los Angeles, Cal. |
| 1887 | Aug. | Leo Daft........... | .... | 1 | ........ | Mansfield, O. |
| 1887 | Aug. | F. J. Sprague....... | .... | 1 | ........ | St. Joseph, Mo. |
| 1887 | Sept. | F. E. Fisher........ | .... | 1 | ........ | San Jose, Cal. |
| 1887 | Sept. | S. H. Short......... | 1.0 | 2 | 1–18 | Columbus, O. |
| 1887 | Nov. | S. H. Short......... | .... | ...... | ........ | Huntington, W. Va. |
| 1887 | Oct. | W. M. Schlesinger.. | .... | ...... | ........ | Philadelphia, Pa. |
| 1887 | Oct. | C. F. Adams........ | 4.0 | 3 | ........ | Wichita, Kansas. |
| 1887 | Oct. | C. J. Van Depoele.. | 7.0 | 2 | 2–7 | St. Catharines, Ont. |
| 1887 | Oct. | Leo Daft........... | 4.0 | 18 | 1–12 | Asbury Park, N. J. |
| 1887 | Nov. | John C. Henry...... | 3.0 | 9 | 1–20 | San Diego, Cal. |
| 1888 | Jan. | Leo Daft........... | 1.0 | 2 | 2–7 | Ithaca, N. Y. |
| 1888 | Jan. | Bentley-Knight..... | 4.4 | ...... | ........ | Allegheny City, Pa. |

## PRACTICAL STREET RAILWAYS.

**The first practical electric street railway** embodied many of the essential features of modern practice. It was installed by the Sprague Electric Railway & Motor Co. for an 11-mile railway, with 10 per cent. grades, at Richmond, Va., and was operated in February, 1888. Energy was furnished from a central station by a 300-h.p. steam engine and a 450-volt direct-current, belted generator, and was transmitted by copper conductors to small cars, each equipped with two 7-h.p. series-wound motors. Thirty cars were in operation by July, 1888.

Mr. Frank J. Sprague in the Transactions of the International Electric Congress, St. Louis, 1904, Vol. III, p. 331, has summarized the features of this now historic road at Richmond.

"Distribution was effected by an overhead line circuit over the center of the track, reinforced by a continuous main conductor, in turn supplied at central distributing points by feeders from a constant potential plant, operated at about 450 volts, with reinforced track return. The current was taken from an overhead line, at first by fixed upper-pressure contacts, and subsequently by a wheel carried on a pole supported over the center of the car and having free, up-and-down, reversible movement. The motors were centered on the axles, and geared to them, at first by single, and then by double-reduction gearing, the outer ends being spring-supported from the car body so that the motors were individually free to follow every variation of axle movement, and yet maintain at all times a yielding touch upon the gears in absolute parallelism. All the weight of the car was available for traction, and the cars could be operated in either direction from either end of the car. The controlling system was at first by graded resistances, afterward by variation of the field coils from series to multiple relations, and series-parallel control of armatures, by a separate switch. Motors were run in both directions with fixed brushes, at first laminated ones placed at an angle, and later solid metallic ones with radial bearings."

**The Development of Practical Street Railways (1888–1896).**—Sprague and his associates now proceeded to convince street railway managers that electric power could be made an economical substitute for animal, steam, and cable traction. Sprague electric railway lines in 1890 included Minneapolis, with 100 cars; St. Paul, 80 cars; Cleveland, 99 cars; St. Louis, 80 cars; Tacoma, 56 cars; Pittsburg, 45 cars; Richmond, 42 cars; in all 89 roads and 2080 motor cars. Electrical Engineer, N. Y., April 30, 1890.

**Thomson-Houston Electric Co.** absorbed the Van Depoele interests in 1888. Its equipment was similar to that used by Sprague, and included two double-reduction, geared motors per car. One distinguishing feature was an excellent controller, for parallel and later for series-parallel operation of motors, in which a magnetic blow-out devised by Elihu Thomson was used. Its first lines were in practical service at Revere Beach, Boston, with one car, July 4, 1888; at Washington, D. C., also at Seattle in 1888; and at Minneapolis in 1889. St. Ry. Jour., 1889, p. 374. Thomson-Houston railway lines in 1890 included Boston, with 127 cars running and 130 ordered; Omaha, 30 cars; St. Paul, 8 cars; in all 61 roads and 431 motor cars. Electrical Engineer, N. Y., April 16, 1890.

**Short Electric Co.,** which had built lines in Denver in 1885, introduced single-reduction, geared and gearless, motors in 1891.

**Westinghouse Electric & Manufacturing Co.,** of Pittsburg, entered the electric railway field in 1890 with single-reduction, geared motors.

**General Electric Co.,** of Schenectady, was formed in 1891 as a consolidation of the Thomson-Houston, the Edison General Electric, the Sprague, and other companies. It obtained the patent rights to the inventions of Van Depoele, Bentley, Knight, Thomson, and Sprague.

**General Electric and Westinghouse Companies** have fostered most of the important American electric railway development since 1893. Patent litigation was stopped when the two companies entered into contracts, in 1896 and 1899, which embodied an exchange of licenses for the joint use of the patents of each company. This interchange was advantageous, for it developed a high degree of co-operation in engineering and in manufacture.

**Allis-Chalmers Co.,** which consolidated E. P. Allis & Co., Bullock Electric Manufacturing Co., and others, about 1896, has furnished much of the power-plant equipment, but little of the electric motor and transmission equipments for railways.

**Conduit railways,** which avoid overhead wires by placing the trolley conductor in a conduit, as in cable railway systems, were successfully installed and operated in Budapest in 1889, in Washington, D. C., in 1895, and in New York in 1896. Few roads have been built in America, because the construction cost exceeds $60,000 per single-track mile.

Conduit roads have been built in Paris, Berlin, Brussels, Vienna, Lyons, Nice, Bordeaux, and London.

**Suburban roads** were a simple development of the street railway. These lines which ran to the territory bordering the limits of the city at first were 3 to 5 miles long, but they now extend even 12 miles. Electric lines running on public streets from the heart of the larger European and American cities gave rise to numerous resident and manufacturing districts situated a considerable distance from the city. The suburban roads resulted from the increase in population and an appreciation by the public of electric transportation. Frequent service, rather than high speed, was the distinguishing feature.

## EXPERIMENTAL WORK.

**Experimental Work of all Kinds was Done until 1895.**—Electricity had now been recognized as an improved power for street railway traction. The cost of the development of equipment was so expensive, however, that it could not be borne by the inventors themselves, or by the manufacturing companies, and much of it was assumed by energetic electric railway companies. To such an extent, indeed, did they burden themselves in this way, that it is remarkable that more of them did not fall into the hands of receivers. Motor equipment which was started with confidence often proved too expensive to operate. It was therefore abandoned, and replaced by an entirely new equipment, sometimes on the suggestion of a manufacturing company, but generally on the recommendation of the electrical engineer and the master mechanic of the operating company. Large sums of money were allowed for experimental purposes by the managers of these pioneer electric railways. Engineers and operators were put on their mettle, and their courage, ingenuity, and ability produced results. It was their opportunity and their duty to progress in this new field. Valuable improvements were readily accepted; apparatus was superseded when better was developed.

In these early days, after the advantages of electric power were apparent, the stockholders and the public were willing to have improvements tried, provided they were not greatly inconvenienced thereby. The manufacturer who now-a-days installs equipment which has not been thoroly tried, or who plans experiments on a large scale at the expense and inconvenience of the public, is condemned.

About 1896, stockholders of electric railways began to receive dividends on their investments. Suitable and economical power plants were built, overhead construction was simplified, insulation of electric motor windings was improved, cost of maintenance of equipment was reduced, service became reliable, and experimental work was lessened.

## A SUMMARY OF DISCARDED IDEAS IN ELECTRIC TRACTION.

**"Count your Failures, not your Successes."**

Many engineering ideas were well tried, and then abandoned, between 1885 and 1895, certain apparatus was found to be unsuitable for ordinary electric railway work; and the following have not since been used:

Batteries, primary and storage.

Over-running trolley; rigid or inflexible trolley contact; two trolleys for city streets.

Unprotected third rail; a third rail between track rails; or a third-rail on elevated posts.

Conduit systems for ordinary electric railway traffic; and surface contact systems, to avoid the use of the trolley.

Track rails for conducting the positive electric current.

Insulation of track rails from the earth.

Rail returns, without adequate bonding at the rail joints.

Use of the soil, rivers, or lakes for a heavy return-current circuit; and the artificial grounding of rails.

Magnetic braking, in ordinary railway-train service.

Magnetic adhesion increasers between rails and wheels to improve the tractive friction or the economy of operation. See Elec. Ry. Journ. Dec. 13, 1909, p. 1240; electric gearing, Elec. World, July 21, 1910, p. 166.

Magnetic systems, wherein alternate attraction and repulsion of magnets produced reciprocating motion, to propel the car.

Motors placed above the floor at the end of passenger cars.

Continuous rotation of armature to retain its kinetic energy.

Connection between armature and car axle by means of a magnetic coupling and quill, or a friction clutch; friction wheels, pulleys, grooves, and disks; wire rope, belt, and chain drive; sprockets and links; cranks near the middle of the axle; bevel gear, worm gear.

Long-distance transmission of direct-current power.

Direct-current series systems.—Short experimented at Denver, 1885. See: Sperry, A. I. E. E., June, 1892; Dalemont, Elec. World, Oct. 14, 1909; Adams, Elec. Ry. Journ., Sept., 1900, page 810.

Regeneration of direct-current power.

Shunt-wound and compound-wound motors; one motor per car.

Control of motors with liquid resistance,—S. D. Field, about 1886. Control of motors with wire resistance on field magnets. Control of motors by a variation of field coils from series to multiple relation,—Field, in 1886; Sprague, in 1888. Control of motor speeds by weakening the field. Control of motors involving two commutators per motor.

Brushes of copper; variation of position of brushes with load or direction of motion; positions other than radial. Relatively large magnetomotive force in direct-current armatures.

Field poles without field coils mounted thereon. The well-known "W. P." motor of 1891 had consequent poles.

Armatures with a large diameter, and fly-wheel effect. Gearless armatures, mounted on the axle without an elastic coupling to absorb switch and crossing shocks, curve thrusts, and track variations.

Motor frames insulated from axles, supports, or rails; motors unprotected from dust, snow, and water of roadbed; motors with unnecessary dead weight, and motor mounting without spring supports.

Mechanical and electrical equipments which were suitable for city or interurban trolley lines, for electric train service.

## INTERURBAN ELECTRIC RAILWAYS (1890).

Interuban railways were a development from the street and suburban railways. In the whole history of transportation, no development has been more important and wonderful than that of the electric interurban railways. It comprises the period from 1890 to 1894, when many short interurban lines were built, then the period of hard times, from 1893 to 1896, when many of these lines were in the hands of receivers, followed by the period, from 1897 to 1907, characterized by gradual increase in the length and capacity of interurban roads, by the use of larger cars and heavier motors, by greater investments and more economical power plants; and, still more recently, by a development which, following steam-railroad practice, involves the use of a complete private right-of-way from terminal to terminal, the operation of motor cars in trains, freight service with motor cars and electric locomotives, and the thru routing of interstate traffic.

Interurbans several years ago reached the limit of their development for local traffic, and their present advance is toward long-haul freight and passenger traffic in competition, or in conjunction, with steam railroads. They fill an important position between the street railway and the steam railroad. Some interurbans are mere trolley lines; others have nearly every function of a railroad.

The development of long interurban roads was impossible until after the introduction of economical long-distance power transmission by the Tesla three-phase, high-voltage system. Niagara power was not sent to Buffalo, only 22 miles away, until November 16, 1896.

Car service has been perfected to outlying amusement parks, and to bathing beaches, where recreation is obtainable at a minimum expense. By improving the facilities for travel, they have provided for a diffusion of city population, and have so developed country life that rural land values have increased.

Interurban passenger service, between many cities of the central and western states, equals, in passenger equipment and speed, that of the

steam railroads of the district; and, in convenience and frequency of service, excel them beyond comparison. The long, vestibuled cars, M. C. B. trucks, high-speed motors, service with a limited number of stops, two-car trains, dining-car service (as on the Chicago & Milwaukee Electric R. R., Aurora, Elgin & Chicago R. R.), roadbeds of stone ballast, standard Tee-rails, a complete private right-of-way including terminals, adequate power houses, telephone dispatching, block signals, and automatic brakes render possible a high degree of speed with absolute safety. These interurban roads are profitable and permanent investments.

Interurban railways are often common carriers, with the right of eminent domain, and are subject to the reasonable control and police power of the municipalities which they connect and thru which they are operated, and to the state railroad commission.

The historical development in America is now tabulated briefly.

INTERURBAN RAILWAY DEVELOPMENT, 1890–1910.

| Name of railway. | Terminal cities. | Miles. | Year. |
|---|---|---|---|
| Twin City Rapid Transit | Minneapolis—St. Paul | 9 | 1890 |
| Lake Shore Electric | Sandusky—Norwalk | 17 | 1893 |
| | Toledo—Norwalk | 62 | 1900 |
| | Toledo—Norwalk—Cleveland | 19 | 1902 |
| Cleveland, Berea, Elyria | Cleveland—Berea | 14 | 1894 |
| | Cleveland—Berea—Oberlin | 34 | 1901 |
| Akron, Bedford & Cleveland | Cleveland—Akron | 35 | 1895 |
| (the first real interurban) | Cleveland—Akron—Canton | 58 | 1901 |
| International Traction | Buffalo—Niagara Falls | 22 | 1895 |
| ........................ | Lowell—Lynn, Mass | 26 | 1896 |
| Minneapolis St. Paul Suburban. | St. Paul—Stillwater | 23 | 1898 |
| Puget Sound Electric | Seattle—Tacoma | 34 | 1902 |
| Boston & Worcester | Boston—Worcester | 46 | 1903 |
| Terre Haute, Ind. & Eastern | Terre Haute—Indianapolis | 72 | 1906 |
| | Terre Haute—Indianapolis—Richmond. | 140 | 1907 |
| Spokane & Inland Empire | Spokane—Moscow, Idaho | 91 | 1907 |
| Fort Wayne & Wabash Valley. | Ft. Wayne—Lafayette | 114 | 1907 |
| Indianapolis & Columbus, and Indianapolis & Louisville. | Indianapolis—Louisville, Ky | 117 | 1907 |
| Indiana Union Traction | Indianapolis—Ft. Wayne | 124 | 1907 |
| Ohio Electric Railway | Ft. Wayne—Lima—Toledo | 137 | 1907 |
| | Toledo—Lima—Dayton, O | 164 | 1907 |
| | Toledo—Lima—Columbus, O | 187 | 1909 |
| Western Ohio Electric | Toledo—Dayton, Ohio | 162 | 1907 |
| Illinois Traction | St. Louis—Springfield—Peoria | 172 | 1909 |
| | St. Louis—Springfield—Danville | 2[illegible]7 | 1908 |

INTERURBAN RAILWAY DEVELOPMENT, 1890–1910.—Continued.

| Name of railway. | Terminal cities. | Miles. | Year. |
|---|---|---|---|
| Several companies | Toledo—Dayton | 162 | 1908 |
| *Thru service* | Toledo—Columbus, Ohio | 187 | 1908 |
| | Chicago—Freeport, Ill | 125 | 1908 |
| | Indianapolis—Michigan City, Ind. | 173 | 1910 |
| | Cleveland—Lima, Ohio | 160 | 1910 |
| | Cleveland—Detroit | 175 | 1910 |
| | Detroit—Kalamazoo | 145 | 1910 |

See: "Historical Interurban Roads," Elec. Ry. Journ., 1909, p. 571.

Exclusive of street railways, there are in Indiana 2300 miles, in Ohio 2600 miles, and in Illinois 1500 miles of interurban road.

Illinois Traction Company has the longest interurban routes and the heaviest freight service; and has operated sleeping cars for six years.

Indianapolis is the great interurban railway center.

Pacific Electric Railway has 560 miles of track, operates one- to five-car passenger trains, and 58 freight trains, out of Los Angeles daily, on fourteen 10- to 40-mile electric routes.

INTERURBAN RAILWAY PASSENGER TRAFFIC, 1910.

| Name of principal city. | Population in 1910. | Radial routes. | Cars daily. |
|---|---|---|---|
| Los Angeles | 319,000 | 14 | 650 |
| Indianapolis | 233,000 | 12 | 318 |
| Cleveland | 560,000 | 8 | 155 |
| Toledo | 168,000 | 8 | 173 |
| Detroit | 466,000 | 7 | 190 |
| Dayton | 116,000 | 7 | 155 |
| Rochester | 218,000 | 6 | ... |
| Buffalo | 424,000 | 5 | ... |
| Columbus, O | 181,000 | 8 | 116 |
| Ft. Wayne | 64,000 | 5 | 100 |
| Milwaukee | 374,000 | 5 | ... |
| Minneapolis—St. Paul | 516,000 | 5 | 100 |

The development of the most important interurban railways in each state is shown by the tables which follow.

The order of listing of tables is geographical, east to west.

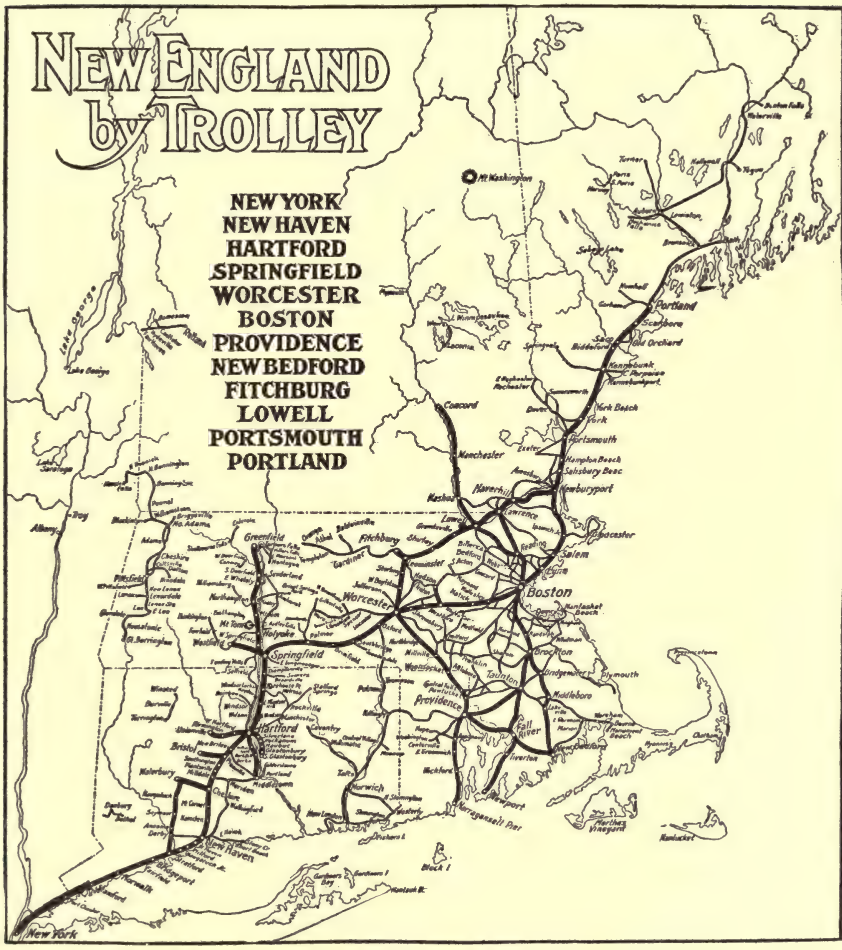


FIG. 6.—MAP OF INTERURBAN LINES IN NEW ENGLAND STATES, 1910.

## INTERURBAN RAILWAYS.

| Name of electric railway. | Name of terminal cities. | Distance between cities. | Track mileage. | |
|---|---|---|---|---|
| | | | Inter-urban. | Grand total. |
| Lewiston, Augusta & Waterville | Lewiston—Waterville | 55 | 83 | 140 |
| Atlantic Shore Line | Portsmouth—Townhouse | 35 | 60 | 110 |
| New Hampshire Electric | Lowell—Portsmouth | 40 | 60 | 110 |
| Massachusetts Electric Co.: | Boston radial lines | | 300 | 933 |
| Boston & Northern Division | | | | |
| Old Colony Southern Division | | | | |
| Boston & Worcester Electric | Boston—Worcester | 46 | 80 | 82 |

INTERURBAN RAILWAYS—Continued.

| Name of electric railway. | Name of terminal cities. | Distance between cities. | Track mileage. Inter-urban. | Track mileage. Grand total. |
|---|---|---|---|---|
| New York, New Haven & Hartford: | | | | 1500 |
| The Rhode Island Company | Providence—Worcester | 45 | 200 | 319 |
| The Connecticut Company | City and interurban | .. | 300 | 780 |
| Shore Line Electric | New Haven—Ivoryton | 52 | 52 | 53 |
| Albany Southern R. R | Albany—Hudson | 37 | 38 | 62* |
| Hudson Valley Ry | Troy—Glen Falls | 48 | 88 | 149 |
| | Saratoga—Warrensburg | 35 | | |
| Delaware & Hudson, and New York Central, and United Traction Co. | Albany—Troy—Cohoes | 11 | 35 | 96 |
| New York Central & Hudson River: | | .. | 500 | 800 |
| New York State Rys Co | Schenectady—Saratoga | 22 | .... | .... |
| The Mohawk Valley Co. | | | | |
| Schenectady Ry | Schenectady—Albany | 16 | 58 | .... |
| Utica & Mohawk Valley Ry | Utica—Little Falls | 23 | 127 | .... |
| West Shore R. R | Utica—Syracuse | 44 | 44 | .... |
| Fonda, Johnstown & Gloversville R. R. | Gloversville—Schenectady | 36 | 65 | 85 |
| Ostego & Herkimer R.R | Oneota—Herkimer | 60 | 58 | 76 |
| Rochester, Syracuse & Eastern | Syracuse—Rochester | 86 | 105 | 165* |
| Buffalo, Lockport & Rochester | Rochester—Lockport | 57 | 57 | 61 |
| International Traction | Lockport—Buffalo | 25 | 88 | 374 |
| | Buffalo—Niagara Falls. | | | |
| Buffalo & Lake Erie | Buffalo—Erie | 88 | 80 | 173 |
| Dominion Power & Transmission | Hamilton—Beamsville—Oakland—Brantford. | .. | 70 | 107 |
| Mahoning & Shenango | Western Pennsylvania | 37 | 70 | 149* |
| Pittsburg, Harmony, Butler & N. C. | Pittsburg—New Castle | 50 | 63 | 67 |
| West Penn Ry | McKeesport—Connellsville | 50 | 80 | 125 |
| Philadelphia & Western R. R | Philadelphia—Norristown | 17 | 17 | 40* |
| Public Service Corporation | Traction lines, New Jersey | 27 | 200 | 720 |
| Lackawanna & Wyoming Valley | Wilkes-Barre — Scranton — Carbondale. | 23 | 45 | 50* |
| Wilkes-Barre & Hazelton | Hazelton—Wilkes-Barre | 31 | 32 | 34 |
| Lehigh Valley Transit | Philadelphia—Allentown | 47 | 100 | 144 |
| Washington, Baltimore & Annapolis | Washington—Baltimore | 41 | 96 | 100 |
| Maryland Electric Rys | Baltimore—Annapolis short line. | 26 | 26 | 35* |
| Cleveland, Painesville & Eastern | Cleveland—Ashtabula | 59 | 45 | 75 |
| Northern Ohio Traction | Cleveland—Canton | 59 | 51 | 215 |
| | Canton—New Philadelphia | 38 | | |
| Cleveland, Southwestern & Columbus | Cleveland—Wooster | 57 | 150 | 243 |
| | Cleveland—Bucyrus | 116 | | |
| Lake Shore Electric | Cleveland—Toledo | 119 | 170 | 215 |
| Ohio Electric | Lima—Fort Wayne | 65 | 450 | 850 |
| | Lima—Toledo | 72 | | |
| | Lima—Defiance | 40 | | |
| | Lima—Springfield—Columbus | 110 | | |
| | Dayton—Union City | 54 | | |
| | Dayton—Richmond | 40 | | |
| | Dayton—Cincinnati | 55 | | |
| | Dayton—Columbus | 76 | | |
| | Columbus—Zanesville | 64 | | |
| Western Ohio | Dayton—Toledo | 150 | 84 | 113 |
| | Findlay—Celina | 68 | | |
| Eastern Ohio Traction | Cleveland—Garrettsville | 50 | 60 | 94 |
| Columbus, Delaware & Marion | Columbus—Marion | 45 | 51 | 77 |

* These roads operate passenger cars in trains, and handle freight under the Master Car Builders rules of interchange.

INTERURBAN RAILWAYS—Continued.

| Name of electric railway. | Name of terminal cities. | Distance between cities. | Track mileage. Inter-urban. | Grand total. |
|---|---|---|---|---|
| Scioto Valley Traction | Columbus—Chillicothe | 47 | 77 | 79 |
| Cincinnati, Georgetown & Portsmouth | Cincinnati—Georgetown | 41 | 40 | 57* |
| Cincinnati & Columbus Traction | Cincinnati—Hillsboro | 51 | 48 | 57 |
| Windsor, Essex & Lake Shore | Windsor—Leamington, Ont | 36 | 36 | 40* |
| Detroit United Ry | Detroit—Port Huron | 74 | 247 | 750 |
| | Detroit—Bay City | 125 | | |
| | Detroit—Toledo | 56 | | |
| | Detroit—Jackson | 76 | | |
| Michigan United Rys | Jackson—Kalamazoo | 68 | 125 | 254 |
| | Jackson—St. Johns | 37 | | |
| Toledo & Western R.R. | Toledo—Pioneer—Adrian | 59 | 80 | 84 |
| Toledo, Fostoria & Findlay | Toledo—Findlay | 52 | 100 | 121 |
| Fort Wayne & Northern Indiana | Fort Wayne—Lafayette | 114 | 150 | 212 |
| Terre Haute, Indiana p'l's & Eastern | Indianapolis—Terre Haute | 72 | 349 | 400 |
| | Indianapolis—Richmond | 69 | | |
| | Indianapolis—Lafayette | 69 | | |
| | Indianapolis—Crawfordsville | 52 | | |
| Indianapolis & Cincinnati | Indianapolis—Greensburg | 49 | 49 | 112 |
| | Indianapolis—Connersville | 58 | | |
| Indiana Union Traction | Indianapolis—Union City | 90 | 314 | 373* |
| | Indianapolis—Bluffton | 99 | | |
| | Indianapolis—Wabash | 92 | | |
| | Indianapolis—Logansport | 80 | | |
| | Indianapolis—Peru | 77 | | |
| | Indianapolis—Fort Wayne | 124 | | |
| Indianapolis, Crawsfordsville & Western. | Indianapolis—Crawfordsville | 45 | 43 | 49 |
| Indianapolis, Columbus & Southern | Indianapolis—Louisville | 117 | 40 | 68 |
| Indianapolis & Louisville. | | | 42 | 55 |
| Indianapolis, New Castle & Toledo | Indianapolis—New Castle | 45 | 90 | 100 |
| Chicago, South Bend & Northern Indiana. | Michigan City—South Bend | 40 | 70 | 117* |
| | South Bend—Goshen | 30 | | |
| Winona Interurban | Goshen—Peru | 65 | 60 | 70* |
| Chicago, Lake Shore & South Bend | South Bend—Pullman | 78 | 78 | 90 |
| Aurora, Elgin & Chicago | Chicago—Aurora—Elgin | 42 | 85 | 160* |
| Illinois Traction | St. Louis—Peoria | 172 | 425 | 560* |
| | Springfield—Danville | 123 | | |
| East St. Louis & Suburban | St. Louis—radial lines | 25 | 100 | 181* |
| Rock Island Southern | Rock Island—Monmouth | 52 | 60 | 82* |
| Chicago & Milwaukee Electric | Evanston—Milwaukee | 76 | 80 | 186* |
| Milwaukee Electric Ry. & Lt | Milwaukee—Watertown | 51 | 100 | 356* |
| | Milwaukee—East Troy | 36 | | |
| | Milwaukee—Burlington | 35 | | |
| | Milwaukee—Kenosha | 33 | | |
| Milwaukee Northern | Milwaukee—Sheboygan | 58 | 54 | 64* |
| Milwaukee Western | Milwaukee—Fox Lake | 60 | 60 | 0 |
| Iowa & Illinois | Clinton—Davenport, Iowa | 40 | 36 | 40 |
| Inter-Urban Ry | Des Moines—Colfax | 24 | 64 | 72 |
| | Des Moines—Perry | 35 | | |
| Fort Dodge, Des Moines & Southern | Fort Dodge—Des-Moines | 70 | 126 | 141* |
| Waterloo, Cedar Falls & Northern | Waterloo—Cedar Falls—Waverly | 24 | 55 | 100* |
| Northern Texas Traction | Sherman—Dallas | 63 | 76 | 86* |
| Colorado & Southern Ry | Denver—Boulder | 29 | 32 | 54 |
| | Colorado Springs—Cripple Creek | 19 | 20 | 20 |

* These roads operate passenger cars in trains, and handle freight under the Master Car Builders' rules of interchange.

INTERURBAN RAILWAYS.—Continued.

| Name of electric railway. | Name of terminal cities. | Distance between cities. | Track mileage. Inter-urban. | Track mileage. Grand total. |
|---|---|---|---|---|
| Salt Lake & Ogden R. R. | Salt Lake—Ogden | 35 | 38 | 55* |
| Washington Water Power | Spokane—Medicine Lake—Cheny | 20 | ... | 108* |
| Puget Sound Electric | Seattle—Tacoma | 37 | 80 | 200* |
| British Columbia Electric | New Westminster—Chilliwack | 64 | 64 | 150* |
| Portland Ry. Light & Power | Portland—Cazadero | 40 | 70 | 472* |
| Oregon Electric Ry | Portland—Salem—Eugene | 70 | 75 | 80* |
| United Rys. Company | Portland—Tillamook | 80 | 80 | 100 |
| Northern Electric | Sacramento—Orville | 97 | 102 | 130* |
| Central California | Sacramento—Stockton | 50 | 50 | 51* |
| San Francisco, Oakland & San Jose | San Francisco—San Jose | 6 | 30 | 64* |
| Southern Pacific Company | Oakland—Berkley | | | 200* |
| Peninsula Ry | San Jose—Palo Alto | | | |
| Visalia Electric Ry | Visalia—Lemon Cove | | | |
| Los Angeles Pacific Company | Los Angeles—Santa Monica, etc. | | | 260* |
| Los Angeles Ry. Corporation | Los Angeles—Coast Cities | 40 | 386 | 600* |

* These roads operate passenger cars in trains, and handle freight under the Master Car Builders' rules of interchange.

THE NEW YORK—WISCONSIN ELECTRIC RAILWAY TRIP.

| Stations. | Miles. | Via. |
|---|---|---|
| Hudson to Albany, N. Y | 38 | Albany Southern R. R. |
| Albany to Schenectady | 16 | Schenectady Railway. |
| Schenectady to Johnstown | 29 | Fonda, Johnstown & Gloversville R. R. |
| Johnstown to Little Falls | 28 | Little Falls and Johnstown R. R. |
| Little Falls to Utica | 23 | Utica and Mohawk Valley. |
| Utica to Syracuse | 49 | West Shore R. R., Oneida Div. |
| Syracuse to Rochester | 86 | Rochester, Syracuse & Eastern. |
| Rochester to Lockport | 56 | Buffalo, Lockport & Rochester. |
| Lockport to Buffalo, N. Y | 25 | International Railway. |
| Buffalo to Erie, Pa | 88 | Buffalo & Lake Erie Traction. |
| Erie to Conneaut, Ohio | 33 | Conneaut & Erie Traction. |
| Conneaut to Ashtabula<br>Ashtabula to Cleveland | 73 | Pennsylvania & Ohio Railway.<br>Cleveland, Ashtabula & Eastern. |
| Cleveland to Toledo | 129 | Lake Shore Electric Railway. |
| Toledo to Ft. Wayne, via Lima | 137 | Ohio Electric Railway. |
| Ft. Wayne to Peru | 55 | Ft. Wayne & Wabash Valley. |
| Peru to Warsaw | 44 | Winona Traction. |
| Warsaw to South Bend | 56 | Chicago, South Bend & North Indiana. |
| South Bend to Pullman | 76 | Chicago, Lake Shore & South Bend. |
| Pullman to Chicago | 14 | Chicago City Railway. |
| Chicago to Evanston | 6 | Northwestern Elevated R. R. |
| Evanston to Milwaukee | 74 | Chicago & Milwaukee Electric R. R. |
| Milwaukee to Sheboygan, or | 61 | Milwaukee Northern Ry. |
| Milwaukee to Watertown | 51 | Milwaukee Electric Ry. |

See route maps in E. R. J., Sept. 24, 1910; Jan. 7, 1911.

# When Traveling in the Central West Use the Electric Lines

LOW RATES—FREQUENT SERVICE—FAST LIMITED TRAINS—NO SMOKE—NO DUST

ACROSS CENTRAL OHIO
on the Limited Trains of the
**OHIO ELECTRIC RAILWAY**

THE OHIO ELECTRIC RAILWAY COMPANY E

Shortest Route Between Zanesville, Newark, Columbus, Springfield, Dayton, Richmond and Indianapolis.

250 MILES IN 9 HOURS TIME

Also Frequent Service Between
Springfield—Urbana—Bellefontaine.
Lima—Ft. Wayne. Lima—Defiance.
Lima—Toledo—Cincinnati—Dayton.
Dayton—Union City.

---

**LIMA ROUTE**

NORTH and SOUTH
**Through Western Ohio**
Fourteen Limited Trains Daily Between
TOLEDO—Bowling Green—Findlay—Lima—Celina—Wapakoneta—Sidney—Piqua—Troy—Springfield—Tippecanoe City and DAYTON

Operated by
W. O. Ry.
T. U. & I. Ry.
D. & T. El. Ry.

163 MILES WITHOUT CHANGE OF CARS

---

## The Southwestern Lines

Connect
**CLEVELAND**
With

Elyria, Beare, Oberlin, Wellington
Norwalk, Lorain, Medina, Wooster
Ashland, Mansfield, Crestline, Galion, Bucyrus

Frequent Service Fast Limited Trains

**THE CLEVELAND, SOUTHWESTERN & COLUMBUS RAILWAY COMPANY**

---

THI&E LINES

375 MILES IN INDIANA and ILLINOIS
Via
**Terre Haute, Indianapolis & Eastern Traction Company**

Hourly Service Between INDIANAPOLIS and Lebanon, Crawfordsville, Frankfort, Lafayette, Danville (Ind.), Greencastle, Brazil, Terre Haute, Sullivan, Paris, Ill.; Martinsville, Greenfield, Knightstown, Richmond and Dayton, O.

FAST LIMITED TRAIN SERVICE
To
TERRE HAUTE, LAFAYETTE, NEW CASTLE, RICHMOND, DAYTON, O., and PARIS, ILL.
Local Freight and Express Service Between All Points

---

THROUGH THE HEART OF ILLINOIS
**ILLINOIS TRACTION SYSTEM**
400 MILES

" CORN BELT LIMITEDS "
ST. LOUIS to SPRINGFIELD, DECATUR, CHAMPAIGN, DANVILLE
223 Miles in 8½ Hours

Limiteds and SLEEPING CARS
St. Louis to SPRINGFIELD, PEORIA, BLOOMINGTON

---

## Cleveland--Toledo--Detroit

LORAIN—SANDUSKY—NORWALK—FREMONT
Via
**Lake Shore Electric Railway**

SEVEN LIMITED TRAINS
180 Miles in 6 Hours

☞ Through Tickets and Low Rates to all Points in Michigan.

---

## The Northern Ohio Traction & Light Co.

6 Limited Trains Daily CLEVELAND—AKRON
3 Limited Trains Daily CLEVELAND—CANTON
Regular Local Trains Every Half-hour

Connections at AKRON for CUYAHOGA FALLS, KENT, RAVENNA, BARBERTON, WADSWORTH.

Connections at CANTON for MASSILLON, CANAL DOVER, NEW PHILADELPHIA, UHRICHSVILLE.

---

## Ft. Wayne & Wabash Valley Tract'n Co.

115 MILES —ALONG— 4 HOURS
**"The Banks of the Wabash"**
In Our Parlor Buffet Cars
Connecting
FT. WAYNE, HUNTINGTON, PERU, WABASH, LOGANSPORT and LAFAYETTE.

"FT. WAYNE-INDIANAPOLIS LIMITEDS"
136 Miles—4½ Hours

---

IUT SYSTEM

## INDIANA UNION TRACTION COMPANY

365 Miles.

SUPERB TRAIN SERVICE
Between
Indianapolis, Anderson, Marion, Wabash, Muncie, Union City, Bluffton, Ft. Wayne, Kokomo, Peru and Logansport.

"INDIANAPOLIS-FT. WAYNE SPECIALS"
"INDIANAPOLIS-MARION FLYERS"
"INDIANAPOLIS-MUNICE METEOR"
NONE SO GOOD

—FAST FREIGHT and EXPRESS SERVICE—

---

## Northern Illinois to Southern Wisconsin

A.E.&C.R.R. Co.

By the great
THIRD RAIL ROUTE
**AURORA, ELGIN & CHICAGO R. R.**

From the heart of Chicago to
WHEATON—AURORA—ELGIN—BELVIDERE
ROCKFORD—FREEPORT—BELOIT—JANESVILLE.
125 Miles. 4½ Hours.

CHAIR CARS———BUFFET SERVICE

FIG. 7.—ADVERTISEMENT USED BY INTERURBAN RAILWAYS.

## COMPETITION WITH STEAM ROADS.

**Competition between steam and electric roads** became active in 1890. Interurban and suburban electric railways took most of the local passenger business, which formerly was a great part of the steam railroad passenger traffic; and the total number of passengers carried by many steam railroads radically decreased between 1895 and 1900.

The paralleling of steam roads by electric roads resulted always in a financial loss to the steam road. Even where the facilities for handling traffic were equal, the public discriminated in favor of electric traction. The freight traffic of electric railways grew; and, as the capacities of the power houses and lines were increased, the handling of carload freight originating along the line was found to be profitable. This naturally created bad feeling on the part of the steam railroads, because of the loss of a monopoly of the mileage and passenger business.

**Action by the steam railroads** then followed:

They leased both their profitable and unprofitable branch lines to electric roads, rather than have these branches paralleled.

They leased their tracks or right-of-way for local electric passenger service but, in most cases, reserved the use of the tracks for thru passenger and freight trains, hauled by steam locomotives. This action gave them greater returns on the capital invested, and it prevented the building of a parallel line, and a division of earnings. The joint use of tracks was thus an economical procedure. Examples of this are noted:

Canadian Pacific R. R. lease of Hull-Aylmer division, near Ottawa, Ontario, for 35 years.

Erie Railroad lease of Buffalo & Lockport Division for 999 years.

Chicago Great Western Railway lease of Sumner-Denver Jct. branch to Waterloo, Cedar Falls & Northern Railway.

Minneapolis and St. Louis R. R., also Chicago, Milwaukee & St. Paul R. R., leases of branch lines to Twin City Rapid Transit Co.

Northern Pacific R. R. lease of Everett branch to Everett Railway and Elec. Co.

Southern Pacific Co. leases of branch lines to Pacific Electric Railway, Peninsula Railway, etc.

Chicago, Rock Island & Pacific R. R. leases of Monmouth-Galesburg 20-mile road, for 25 years to Rock Island Southern Railway.

They electrified their branch lines, to head off trolley competition. An investment of $6,000 to $8,000 per mile, for trolley and electric power equipment, was made by the existing steam road; while not only this investment, but an additional $12,000 to $15,000 would have been required for the road and equipment of a new electric railway. Projected roads, which would be competing or paralleling, were often headed off in this manner by steam railroads.

They familiarized themselves with the use of gasoline power and electric power, and studied their economic advantages for branch lines.

They reduced the passenger fares between competing points.

They purchased competing lines, branch lines, and feeders, and consolidated them, to control the financial or railway situation. Some steam railroads (Boston & Maine, New Haven, New York Central, Delaware & Hudson, Colorado & Southern, Great Northern, Northern Pacific, and Southern Pacific), to protect themselves, have purchased several thousand miles of interurban railways, thus destroying some competition.

New York, New Haven & Hartford R. R. had acquired, to 1909, about 1500 miles of trolley line in New England. The reason for this enormous trolley acquisition was given in 1909 by President C. S. Mellin, as follows:

> "The thought of our company when it first acquired an interest in Massachusetts trolleys was not the suppression of competition, for we do not believe there is any serious competition between the two systems of traction, electric and steam. Rather, it is our thought that all systems will ultimately develop into the electric, and the street railways, so called, become adjuncts to, or supplementary to, the present trunk lines, which are now operated by steam, but which we believe are later going to be transformed into electric lines."

New York Central has purchased about 750 miles of interurban road in the Mohawk Valley. This proved advantageous to the public. The service was bettered by expenditures for double track, terminals, improved electric motive power, more private right-of-way, higher speed, and better management. Close co-operation, the making of one business the auxiliary to the other business, has resulted in better public service. Later on, much will be gained by joint construction and maintenance of power plants. A desire exists to operate two- and three-car trains, and a study is now being made of the local limitations that prevent better electric service, viz., short-sighted city ordinances, short-radius curves, long fenders, weak bridges, etc.

Delaware & Hudson has followed the examples set by other railroads.

> The advantages accruing thru the acquisition of the United Traction Company of Albany, the Hudson Valley Railway (owned by the United Traction Company), the Troy & New England Railway, the Plattsburg Traction Company, and a half interest in the Schenectady Railway (the other interest in which is owned by the Mohawk Valley Company on behalf of the New York Central & Hudson River), can best be understood by showing the relations between these electric roads and the steam railroads controlled by the Delaware & Hudson.
>
> The electric lines furnish a complement to the service provided by the steam railroads; and the full benefit of this is derived when the running schedules of the electric roads are made to conform to those of the steam roads so as to afford the best service possible for the patrons of the respective companies.
>
> The construction of trolley lines, even where paralleling the steam railroads,

may materially increase the traffic on the latter. The steam roads cannot afford to make the frequent stops which are made by the electric lines, and the traffic is mainly new business created by the increased transportation facilities afforded.

Competition between electric and steam roads was the indirect cause of the adoption of electric power by many short steam roads, and of parallel suburban steam roads; and it was the direct cause of the electrification of the following steam roads:

Mersey Railway near Liverpool, 1903.
Lancashire and Yorkshire Railway, 1904.
Manhattan Elevated Railway, New York, 1903.
Some of the elevated roads in Chicago, 1896.

**Reference:**

The result of these electrifications was rapid recovery of gross earnings, a decrease in operating expenses, and the improvement of a bad financial situation.

Lancashire & Yorkshire Railway regained a very large traffic, which was previously taken away by competing electric lines, after it was electrified in 1904, according to the testimony of J. A. F. Aspinwall, General Manager and Engineer, in an address to the Institution of Mechanical Engineers, 1909.

Manhattan Elevated Railroad, operated with the best compound steam locomotives, might have failed, so severe was the competition of the electric railways which paralleled it. After the road was electrified in 1903, the traffic was recovered.

Competition with steam railroads still exists, to a limited extent. Much of the heavier passenger and light freight business of the steam railroads has been taken, and will be held by the long electric railways, until the steam railroads in turn adopt electric traction. Competition in the future will therefore be interesting.

**Patronage Will Depend on the Following Determining Features:** —Routes on a private right-of-way, including city terminals, because schedule speed, not distance, will be paramount. Interurban roads which use the city streets will be excluded from this race.

Accessibility to the starting point and destination of passengers. Probably, in the future, few elevated structures will be allowed on city streets. Many railways will therefore be required to use subways and tunnels under city streets. These tunnels will facilitate the gathering and rapid distribution of freight at terminals.

Frequency, convenience, and comfort in passenger-train service. Facilities for handling traffic with flexible motive power at terminals.

Ownership of the competing, and of the feeding lines.

Economy in train operation.

Freight tariffs will seldom govern in the competition.

**PRIVATE RIGHT-OF-WAY.**

One important development in the history of electric railways was due to the use of a private right-of-way. This became necessary for safe operation at high speeds, and for thru traffic on the interstate roads which, since 1900, have developed so rapidly. Important electric railways on a private right-of-way are not to be classified with interurbans which run along the public highways. The use of a private right-of-way contributed greatly to the development of the following early railways:

Akron, Bedford & Cleveland Railroad, 1895.
Buffalo & Lockport Railway. which leased its 21-mile road, 1898.
Albany Southern Railroad, a third-rail road, 1901.
Seattle-Tacoma Interurban Railway, a third-rail road, 1902.
Wilkes-Barre & Hazelton Railway, a third-rail road, 1903.
Lackawanna & Wyoming Valley Railroad, a third-rail road, 1903.
Scioto Valley Traction Company, a third-rail road, 1904.
Aurora, Elgin & Chicago Railroad, a third-rail road, 1903.

The development is outlined in St. Ry. Jour., Jan. 2, 1904, p. 26.

The first electric railways on a private right-of-way and even branch lines of electrified steam railroads used city streets as terminals so that passengers could be received and delivered nearer the heart of the cities. Important electric railways, which operate two- or three-car trains, now prefer a private right-of-way to their own passenger terminals, and a loop around the cities for the thru freight traffic.

Lack of a private right-of-way, and the use of turn-pikes, highways, and state roads, retard the development of many interurban railways, particularly those in New England and some of those radiating from Albany, Detroit, Indianapolis, Columbus, etc. In these cases the short radius street curves limit the length of cars, the grades require excessive power, the roadbed is crooked and badly drained, the running of trains is prevented, the schedule speed is slow, and the necessary results of these restrictions are limited traffic and poor car service.

Electric roads, in many states, operate under the general state railroad laws, and are authorized to take and appropriate private property for a right-of-way thru, under, and across any land needed for the construction, maintenance, and operation of the road, and may do so by instituting condemnation proceedings. Consult: U. S. Census Report on Street and Electric Railways, 1902, p. 136.

**Advantages of a Private Right-of-way are Found to be:**

High speed, which is practical from terminal to terminal. This secures business in competition. In heavy electric traction, running time is often as important as frequent service. The suburbs of large cities are determined and measured on a

*time basis* instead of by distances. Steam railroads which have electrified their suburban lines have an opportunity to get, or regain, the bulk of the passenger traffic, particularly where the electric zone extends more than 15 miles from the city. High speed on city streets and country highway is dangerous.

Dead mileage on city loops and streets is eliminated.

Cars used on a private right-of-way have the standard width of 10 feet, thus allowing comfortable cross seats.

Trains of two or more passenger cars can be operated. There is a reasonable objection to two- and three-car trains on city streets, and they are seldom allowed.

Third rails and high-voltage trolleys can be utilized to decrease the cost of transmissions and the loss of power.

Track construction may be better, or may cost less, because of the route, the drainage, the higher elevation, and the absence of paving. Tee-rails supersede girder rails, and the special work required is cheaper.

Maintenance is decreased. Cost of tie renewals, bridge up-keep, and track repairs is lower. Removal of snow is facilitated. Maintenance of equipment per seat-mile and per ton-mile is less with longer cars, heavier switch work, and long-radius curves.

Subways and tunnel roads at the terminals may deliver freight and passengers to convenient points in the city.

Franchises are not required from counties and from some municipalities, altho reasonable speed and police restrictions may be enforced. Delays, uncertainty, expense, limitations, and unreasonable restrictions may be avoided.

Freight and express traffic may be facilitated. There is a reasonable objection to freight cars on city streets, day or night.

Trainmen's wages, the heaviest expense per car mile, per car-hour, or per ton-mile are reduced by the increased schedule speed, and by the use of two- and three-car trains. Accident and legal expenses are also reduced.

Cost of power is decreased. A two- or three-car train requires from 70 to 60 per cent. of the power of a single car train, per ton moved. The power required is decreased also because the grades and sharp curves of the city streets are avoided and because the cleaner Tee-rail reduces the frictional resistance. The load factor of the power plant is improved when freight train service is added.

**Economic results from these advantages** are the ability to secure and retain business, on the time-honored principle that "facilities create traffic," and the reduced cost of handling a given volume of business, by utilizing the physical advantages incident to the private right-of-way.

**Disadvantages to be noted** are that passengers may not be delivered at convenient terminals; public bridges may not be utilized; the cost of the road on the private right-of-way may be higher; and transfers to other lines or roads may not be practicable.

**The importance of the matter** is shown by the U. S. Census reports on electric railways. In 1902 there were 3802 miles on a private right-of-way, or 16.8 per cent. of the total electric mileage, while in 1907 this had increased to 10,972 miles, or to 31.9 per cent. of the total electric mileage. The importance of the train service determines the percentage of the mileage on a private right-of-way.

Many steam railroads have now been changed to electric, and their

track is on a private right-of-way, including good private terminals in the heart of the cities.

### ELEVATED RAILWAYS.

Elevated railways have adopted electric motive power for their train service, to utilize the physical advantages of electric traction. The capacity of the elevated roads was thereby increased, because longer electric-car trains could be operated, and at higher speeds. The shearing and deflecting strains on the structure and the vibration due to reciprocal strokes of the engine were lessened. The dirt, ashes, and gas, and the noise from the exhaust steam of a locomotive, were eliminated.

Many elevated railroads experimented with electricity prior to 1890, but most of these tried electric locomotives. Rapid progress was made after the multiple-unit car control system was developed in 1898. Third-rail conductors, motor-car trains, and the 600-volt, direct-current system, are now used by all elevated railways.

At the Columbian Exposition, Intramural R. R., at Chicago, in 1893, fifteen 4-car trains were successfully operated, on a 6-mile elevated road, using the electric locomotive-car scheme.

Liverpool Overhead Railway was the first elevated railway in England to use electric power. This was in 1893.

Metropolitan West Side Elevated R. R., Chicago, equipped its road in 1895, using the electric locomotive-car plan and, later, the motor-car plan.

The Brooklyn Bridge and its terminals followed in 1896.

Chicago and Oak Park Elevated R. R., formerly the Lake Street Elevated R. R., began operation on the electric-locomotive plan in 1896, but soon changed to the motor-car plan.

South Side Elevated R. R., Chicago, was originally equipped with steam locomotives. It was one of the first railroads operating trains of cars to adopt electric propulsion. About 150 tons of anthracite coal, costing about $4.50 per ton, were burned daily by the steam locomotives. When electricity was adopted, in 1898, the amount of coal burned in the power house was less in tonnage than the coal burned in the locomotives, and cost less than $1.50 per ton. This one saving helped to get the railroad out of the hands of a receiver.

Manhattan Elevated Railroad, New York City, a large steam railroad, did not adopt electric traction until 1902.

Data on length and equipment of elevated roads follow.

TRAIN SERVICE ON ELEVATED AND UNDERGROUND ROADS.

| Name of electric railroad. | Cars per train. | Trains per hour. |
|---|---|---|
| Boston Elevated | 6 to 8 | 35 |
| Manhattan Elevated | 5 to 8 | 60 |
| New York Subway | 8 to 10 | 32 |
| Hudson and Manhattan | 5 to 6 | 40 |
| Brooklyn Union Elevated | 6 to 7 | 60 |
| Philadelphia Rapid Transit | 2 to 5 | 20 |
| Chicago Union Elevated loop | 5 to 6 | 150 |
| Metropolitan District, London | 8 to 9 | 68 |
| Baker Street and Waterloo, London | 4 to 6 | 72 |
| Charing Cross, Euston & Hempstead | 4 to 5 | 80 |
| Great Northern, Piccadilly & Brompton | 5 to 6 | 60 |

## THIRD-RAIL LINES.

Third-rail lines represent an interesting development. Overhead trolley wires at first were often too frail or too expensive for direct-current, 600-volt, railway train service, and this led to the adoption of a rugged third-rail conductor of steel with large capacity and ample contact area. The chronology is briefly outlined.

In 1879, Siemens and Halske operated a short 180-volt, third-rail line at the Berlin Exposition; in 1883, a 6-mile, 250-volt, third-rail line for the Portrush Railway in Ireland.

In 1880, Edison used a third rail for his Menlo Park locomotives. Elec. World, June 10, 1899; Sprague, A.I.E.E., May, 1899, p. 245.

In 1883, Daft built the 12-mile Saratoga & Mount McGregor, and, in 1885, a 2-mile, 130-volt road at Baltimore.

In 1893, Intramural Railway, of the World's Columbian Exposition, at Chicago, developed by H. M. Brinckerhoff, was the first commercial third-rail road of the present type. This 6-mile elevated road used direct current at 500 volts.

In 1895, Metropolitan West Side Elevated Railway, of Chicago, was the first permanent electric third-rail line. The insulation first used was paraffined wood. Other elevated roads followed.

In 1895, Baltimore and Ohio R. R. adopted a trough-shaped overhead contact line, flexibly suspended from the roof of the Baltimore tunnel. The contact shoe pressed downward on flanges of Z-bars. Mechanical troubles at curves, bad alignment, rigidity, and arcing, due to rapid corrosion from coal gas and steam from locomotives, caused the company to abandon the plan. It then placed an expensive sectionalized third rail

near the track, which in turn was abandoned for a simplified type of third rail on reconstructed granite blocks. Later the clamps for the rails were corroded. At present the rail rests on porcelain without clamp fastenings.

In 1896, New York, New Haven & Hartford R. R. applied the third rail on its Nantasket Beach line, near Boston. The insulated third rail was placed near the center of the track. This was followed by 40 miles of road in Connecticut, equipped with the third rail at the side of the track. (St. Ry. Journ., June, 1897; Sept., 1898; Aug. 25 and Sept. 8, 1900.) The third rail was badly placed and unprotected. Some fatalities and injuries followed and, by a decree of the Superior Court, June 13, 1906, the Company was compelled to abandon all third rail operation in Connecticut, and revert to steam locomotives.

In 1901, Albany & Hudson R. R. installed the finest third-rail road in the country, on a private right-of-way between Albany and Hudson.

In 1903, Wilkes-Barre and Hazelton R. R. installed a third-rail line for heavy traction. The line is 26 miles long, on a private right-of-way. The rail was protected by pine guards. St. Ry. Journ., March 7, 1903.

In 1907, West Jersey & Seashore R. R. built an extensive protected third-rail contact line, 65 miles long, on its double track road between Camden and Atlantic City, N. J. The application was of a substantial character, for passenger train service comparable with ordinary steam railroad traffic.

In 1907, New York Central R. R. began the use, at New York, of an under-running third-rail contact. Heretofore all large installations had used the over-running contact. The scheme was patented by Sprague and Wilgus, under whose direction the installation was made. St. Ry. Journ., Nov. 9, 1907, p. 954.

In 1908, Hudson & Manhattan R. R., and Interboro Rapid Transit, adopted for a third rail an inverted channel in 60-foot lengths, weighing 75 pounds per yard.

In 1909, Pennsylvania Railroad, for its six tunnels and thirty-six parallel tracks at its New York terminal, and for part of the Long Island Railroad, used a 150-pound Tee-rail.

See third rail, under "Transmission and Contact Lines."

Statistical tables which follow show the extent, present status, and importance of railways using the third-rail conductor.

THIRD–RAIL LINES IN AMERICA.

| Name of railway. | Year service started. | No. of motor cars. | Present third-rail mileage. | Location above track-rail. | Gage line to third-rail center. |
|---|---|---|---|---|---|
| Boston Elevated | 1901 | 225 | 26 | 6.00″ | 20.375″ |
| New York, New Haven & Hart.: | | | | | |
| Nantasket Beach Division | 1896 | 0 | 0 | 1.50 | Center |
| New Berlin, Connecticut | 1897 | 0 | 0 | 1.50 | Center |
| New York Division, leased | 1908 | 4<br>43 L | 50 | 2.75 | 28.25 |
| Brooklyn Rapid Transit, Elev. | 1895 | 659 | 107 | 6.75<br>6.00 | 20.50<br>22.25 |
| Manhattan Elevated R. R. | 1902 | 895 | 119 | 7.50<br>4.50 | 20.75<br>22.00 |
| Interborough Rapid T., Subway. | 1904 | 910 | 85 | 4.00 | 26.00 |
| Hudson & Manhattan R. R. | 1908 | 200 | 18 | 4.00 | 26.00 |
| New York Central: | | | | | |
| Hudson and Harlem Divisions. | 1906 | 137<br>47 L | 50 | 2.75<br>3.50 | 28.25<br>27.50 |
| West Shore R. R.: | | | | | |
| Utica-Syracuse Division | 1906 | 21 | 114 | 2.75 | 32.00 |
| Pennsylvania R. R.: | | | | | |
| Long Island R. R. | 1903 | 322 | 150 | 3.50 | 27.50 |
| West Jersey & Seashore | 1907 | 80 | 144 | 3.50 | 27.50 |
| New York Terminal Division | 1910 | 33 L | 95 | 3.50 | 27.50 |
| Albany Southern R. R. | 1900 | 45 | 58 | 6.00 | 27.00 |
| New York, Auburn & Lansing | 1911 | ........ | 40 | .......... | ........ |
| Philadelphia Rapid Transit | 1904 | 150 | 18 | 6.00 | 23.00 |
| Philadelphia & Western | 1907 | 28 | 40 | 6.00 | 26.625 |
| Wilkes-Barre & Hazelton | 1903 | 6 | 32 | 5.00 | 28.00 |
| Lackawanna & Wyoming Valley. | 1903 | 30 | 50 | 3.00 | 20.375 |
| Baltimore & Ohio R. R. | 1895 | 12 L | 9 | 3.30 | 30.35 |
| Michigan Central R. R., Detroit. | 1910 | 6 L | 19 | 2.75 | 28.25 |
| Scioto Valley Traction | 1904 | 17 | 79 | 6.00 | 28.00 |
| Michigan United Railway | 1904 | 40 | 100 | 6.00 | 21.205 |
| Grand Rapids, Grand Haven & M. | 1902 | 30 | 49 | 5.75 | 20.375 |
| Intramural R. R., Chicago | 1893 | 15 | 0 | 13.00 | 30.000 |
| Chicago & Oak Park Elevated | 1896 | 45 | 20 | 6.50 | 20.125 |
| Metropolitan West Side Elevated. | 1895 | 225 | 57 | 6.25 | 20.125 |
| Aurora, Elgin & Chicago R. R. | 1902 | 115 | 126 | 6.31 | 20.125 |
| Northwestern Elevated R. R. | 1900 | 288 | 60 | 6.50 | 20.125 |
| South Side Elevated R. R., Chi. | 1898 | 200 | 47 | 6.75 | 20.125 |
| Twin City Rapid Transit | 1907 | 2 L | 1 | 6.00 | 30.00 |
| Puget Sound Electric | 1902 | 100 | 60 | 7.50 | 20.00 |

THIRD-RAIL LINES IN AMERICA—Continued.

| Name of railway. | Year service started. | No. of motor cars. | Third-rail mileage. | Location above track-rail. | Gage line to third-rail center. |
|---|---|---|---|---|---|
| Northwestern Pacific R. R., Cal. | 1908 | 37 | 23 | 6.00 | 27.00 |
| Central California Traction; uses 1200 volts, on third rail. | 1909 | 10 | 50 | 3.00 | 29.50 |
| Northern Electric Ry., California. | 1906 | 42 | 130 | 5.56 | 25.50 |
| M. C. B. recommendation. | 1904 | Over | contact | 3.50 | 27.00 |
| | | Under | contact | 2.75 | 27.00 |

The last line is the longest. It handles heavy freight and passenger traffic.

THIRD-RAIL LINES IN EUROPE.

| Name of railway. | Year service started. | No. of motor cars. | Third-rail mileage. | Location above track-rail. | Gage line to third-rail center. |
|---|---|---|---|---|---|
| Central London | 1900 | 68 | 13 | 1.50 | Center |
| London Electric Ry.: | ........ | ........ | 168 | 3.00 | 16.00″ |
| Metropolitan District | 1904 | 197 | ...... | .......... | ........ |
| Baker Street & Waterloo | 1906 | 36 | ...... | .......... | ........ |
| Charing Cross, E. & H. | 1907 | 60 | ...... | .......... | ........ |
| Great Northern, P. & B. | 1906 | 72 | ...... | .......... | ........ |
| Great Northern & City | 1904 | 35 | 7 | .......... | 11.25 |
| Great Western, M. & W. L. | 1906 | 40 | 11 | 3.00 | 16.00 |
| Metropolitan Ry., London | 1905 | 130 | 60 | 3.00 | 16.00 |
| City & South London | 1890 | 52 L | 15 | 1.25 | 14.50 |
| Waterloo & City | 1898 | 20 | 3 | level | Center |
| Mersey Railway | 1903 | 24 | 10 | 6.00 | 22.25 |
| Lancashire & Yorkshire Liverpool-Southport | 1904 | 80 | 82 | 3.00 | 19.25 |
| Liverpool Overhead | 1893 | 44 | 13 | 1.50 | Center |
| North-Eastern Railway | 1904 | 62 | 82 | 3.25 | 19.25 |
| Berlin Overhead and | 1897 | 139 | 16 | 7.10 | 13.25 |
| Underground. | 1907 | | 10 | 19.05 | 16.00 |
| Berlin-Gross Lichterfelde | 1903 | 24 | 15 | 12.625 | 33.50 |
| Fribourg-Morat, Switzerland | 1902 | ........ | 18 | 5.375 | 26.00 |
| Paris-Metropolitan | 1900 | 548 | 63 | 5.75 | 12.75 |
| Paris-Lyons-Mediterranean | 1900 | ........ | 40 | 9.00 | 23.00 |
| Paris-Orleans | 1900 | 100 | 46 | 7.875 | 23.625 |
| | | 11 L | | 6.00 | 22.00 |
| Paris-Versailles (Western) | 1901 | 10 L | 16 | 7.875 | 25.625 |
| Paris North-South Electric | 1910 | ........ | 4 | .......... | ........ |
| Fayet-Chamonix-Martigny | 1902 | 80 | 34 | 9.055 | 23.00 |
| Mediterranean Ry. Milan-Varese-Porto Ceresio | 1901 | 20 | 81 | 7.60 | 26.50 |

## SUBWAYS AND TUNNELS.

Subways and underground roads have also found electricity advantageous, primarily because of the absence of smoke, gas, and condensed steam. In underground roads and subways, motor-car trains are used for passenger service; while in tunnels locomotives are generally employed for freight and passenger train haulage.

Underground railways in England, called tube railways, have a total length of 100 miles, all double track. The tubes are deep, and require 150 passenger elevators at fifty stations.

Paris subways are important, and they have a greater traffic than the New York Interborough Subway. Elec. Ry. Journ., Dec. 11, 1909.

New York Central R. R. terminal at New York, and the Boston terminal stations, have been arranged for the operation of motor-car trains in sub-tracks below the elevation of the main-line tracks.

Subways and tunnels under city buildings and streets, to reach a convenient city terminal, for the purpose of delivering freight and passengers, are a recent development. (Hudson & Manhattan R. R.)

Subways have been considered for freight service at New York City; also for local passenger service at Montreal, Toronto, Pittsburg, Cleveland, Cincinnati, Chicago, Minneapolis, St. Louis, and Los Angeles.

Cost of subways at New York with equipment is $1,100,000 per mile of single track. Subways without motive power equipment cost from $600,000 to $900,000 per mile. Cost of tunnels under rivers without equipment varies from $1,200,000 to $1,800,000 per mile. Elevated structures, without equipment, cost $200,000 to $300,000 per single-track mile; conduit railway lines without equipment, from $80,000 to $120,000 per single-track mile. New York Rapid Transit Commission Report of 1908.

**Tunnel roads** now use electric traction. Steam locomotive drivers slipped on the greasy rails in tunnels. Condensed steam and soot deposits were a nuisance. Gas and steam-laden atmosphere required long blocks, and was a menace to safe operation. Exhaust fans seldom successfully cleared the tunnel of gas and smoke. Oil firing was a poor expedient, and coke formed a suffocating gas. Formerly trains waited for hours until the tunnel was cleared of gas pockets, formed by variable winds; and if traffic was dense, congestion followed. The capacity of tunnels, in cars per day, was generally doubled by the introduction of electric hauling of the freight and passenger trains.

UNDERGROUND ROADS USING ELECTRIC POWER.

| Name of railroad. | Route miles. | Double track. | Grade p. c. | Inside section. Height. | Inside section. Width. | Elec. power. |
|---|---|---|---|---|---|---|
| Boston Subway | 4.4 | Yes | ...... | 20.5 | 23.3 | 1895 |
| New York Interboro Subway | 25.0 | 2 and 4 | ...... | 11.5 | 12.4 | 1904 |
| Philadelphia Rapid Transit | 1.4 | Yes | ...... | 14.5 | 13.3 | 1905 |
| Illinois Tunnel, Chicago | 62.0 | 2 and 4 | ...... | 7.5 | 6.0 | 1900 |
| Central London | 6.5 | Yes | ...... | 11.7 | diam. | 1895 |
| London Electric | 100.0 | Yes | ...... | 11.7 | diam. | 1905 |
| City & South London | 3.4 | Yes | ...... | 10.5 | diam. | 1890 |
| Paris—Orleans | 2.4 | Yes | 1.1 | ........ | ........ | 1900 |
| Paris—Metropolitan | 31.0 | Yes | ...... | 15.0 | 23.4 | 1900 |
| Budapest, Hungary | 2.3 | Yes | ...... | 9.0 | 20.0 | 1896 |
| Berlin, City of | 12.0 | Yes | ...... | ........ | ........ | 1902 |
| Hamburg, City of | 4.0 | Yes | ...... | ........ | ........ | 1910 |
| Boston & Maine R. R. Hoosac Tunnel, Mass. | 4.75 | Yes | 0.3 | 22.7 | 24.0 | 1911 |
| Lackawanna and Wyoming Valley, Scranton Tunnel | 1.00 | No | 1.0 | 22.0 | 17.0 | 1905 |
| Hudson & Manhattan R. R. | 2.50 | Yes | ...... | 15.25 | diam. | 1908 |
| Pennsylvania R. R.: | 15.0 | .... | ...... | 19.00 | diam. | 1910 |
| New York to Hoboken, N. J. | ...... | Yes | 1.30 | | | |
| New York to Long Island | ..... | 4 | 1.92 | | | |
| Belmont Tunnel, East River | ...... | Yes | ...... | ........ | ........ | 1911 |
| Interborough Rapid Transit New York to Brooklyn. | ...... | Yes | ...... | 15.0 | 12.5 | 1908 |
| Baltimore & Ohio R. R. Baltimore Belt Line. | 1.2 | Yes | 1.5 | ........ | ........ | 1895 |
| Grand Trunk Railway Port Huron-Sarnia Tunnel. | 1.2 | No | 2.0 | 19.80 | diam. | 1908 |
| Michigan Central R. R. Detroit River Tunnel. | 1.5 | Yes | 2.0 | 20.0 | diam. | 1910 |
| Great Northern Railway Cascade Tunnel, Wash. | 2.6 | No | 1.7 | 22.0 | 16.0 | 1909 |
| Spokane & Inland Empire Local tunnel at Spokane. | 0.8 | Yes | ...... | ........ | ........ | 1910 |
| Severn, England | 4.3 | No | ...... | 19.0 | 28.0 | No |
| Mersey, England | 4.0 | Yes | 2.0 | 19.0 | 26.0 | 1903 |
| Bernese Alps Ry. Loetschberg Tunnel. | 8.5 | Yes | 2.7 | 19.8 | 26.4 | 1911 |
| Swiss Federal Ry. Simplon Tunnel. | 12.3 | No | 0.7 | 19.0 | 16.5 | 1908 |
| St. Gothard, Switzerland | 9.3 | Yes | 0.5 | 20.5 | 26.0 | No |
| Mont Cenis, Switzerland | 7.9 | Yes | 3.0 | 20.5 | 26.0 | 1910 |
| Arlberg, Austria | 6.5 | Yes | 1.5 | ........ | ........ | No |
| Italian State Ry. Giovi near Genoa. | 2.5 | Yes | 2.9 | ........ | ........ | 1909 |

Height noted is from the top of track tie to crown of arch.

The handling of freight trains thru tunnels was accompanied by great danger. In the event of a train breaking in two, on the level or a grade in the tunnel, the time necessary to re-couple and release the automatically applied brakes, or to repair a defect, exceeded the time interval within which the steam locomotive could safely stay in the tunnel without suffocating the train crew. Electric trains can remain in the tunnel as long as required, and trainmen have such confidence in electrical operation that the long tunnel has ceased to be a terror to them.

Carrying capacity of tunnels was often doubled by electrification, because of the shorter blocks, absence of gases, and much greater loads on the grades. Time was saved and delays were avoided.

All long tunnels with heavy traffic now use electric traction.

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## MOTOR-CAR TRAINS.

Steam railroads in passenger and freight service use multi-car trains with a locomotive at the head of the train. Electric railways in heavy passenger service use motor-car trains with motors under each car, or under some of the cars of the train. There had been a rapid development in motor-car train service, caused in part by the competition between electric roads. A passenger at once notices the great difference between the good riding qualities, equipment, comfort, and service furnished

in a 2- or 3-car electric train, and the riding qualities and service of an ordinary interurban car.

Motor-car passenger trains are seldom allowed on the city streets. Exceptions are to be noted on some lines of the Connecticut Company, the Rhode Island Company, and at Hudson, Buffalo, Louisville, Milwaukee, Des Moines, Seattle, and Tacoma.

Motor-car trains are now used by all elevated and underground roads, and in important suburban and interurban passenger service; and also for important freight service in trains on North-Eastern Railway of England, Long Island R. R., West Jersey & Seashore, and some interurban roads.

Control of the many motors used on a motor-car train was difficult. At first one controller was placed at each end of the train, and the main current was carried by heavy electric cables from motor car to motor car. Then control systems called "master controller" and "double header" were developed by Parshall, Darley, and others for motor-car trains; but the Sprague multiple-unit control scheme placed the development on an economical and on an operative basis. The scheme embraces secondary control, and main currents do not enter the motorman's controller. It was first used in 1898, by South Side Elevated R. R., of Chicago, for 120 cars. Westinghouse and General Electric Companies followed with multiple-unit control equipments on the Brooklyn Elevated Railway, in 1898 and 1900. The first British railway to use the multiple-unit control was the City and South London, in 1904.

Car equipment and multiple-unit control systems are detailed in the Chapter on "Motor-Car Trains."

## MOUNTAIN-GRADE LINES.

Mountain-grade lines have now been radically improved by the use of electric power on about 200 miles of road in Europe, particularly in and near Switzerland. In America, however, not a single trunk-line railroad has equipped its mountain grades with electric power, altho the Chicago, Burlington & Quincy R. R. has so equipped a branch between Leads and Deadwood, S. D., 4 miles long on a heavy grade, and the Colorado Springs & Cripple Creek District Ry. of the Colorado & Southern R. R., has installed electricity on an interurban line 18 miles long which has an average grade of 3 per cent. Great Northern Railway installation was for a tunnel and yards.

In mountain-grade service, steam locomotives show low economy. The speed is but from 6 to 10 miles per hour; and on single track, congestion of traffic frequently cannot be avoided. The remedy for much of the trouble was found in the use of electric power, which greatly increased the train hauling and track capacity, and improved the economy of operation. Long tunnels and snow sheds are common in the mountains.

Water power is frequently abundant. The regeneration of electrical energy has been worked out, and is used in America and in Europe to promote safety on down-grade lines by preventing the heating of brakes-shoes and the straining of the brake rigging, and the use of air is restricted to cases of emergency.

A list of heavy mountain grades, where water power and electric locomotives could be used advantageously, is given under Chapter XIV, in which there is a complete discussion of the subject.

### RAILROAD TERMINALS.

Railroad terminals of some of the important railroads and scores of steam terminal railways within large cities have now been electrified. See lists of electric locomotives. Primarily this was for the purpose of obtaining better freight terminal facilities, better motive power, and economy in operation. Incidentally with electric power the smoke nuisance, the fire risk, the noise from exhaust steam, and the fogging of signals by steam are absent. The use of motor-car trains, for suburban passenger service from these terminals, is now an approved practice.

RAILROADS USING ELECTRIC TRACTION AT TERMINALS.

Paris-Orleans, at Paris, 1900.
Lancashire & Yorkshire Railway, England, 1904.
New South Wales Railway, Australia, 1906.
Havana Central Railroad, Cuba, 1906.
Baltimore & Ohio Railroad, Baltimore tunnel yards, 1895.
New York Central & Hudson River Railroad, New York, 1906.
New York, New Haven & Hartford Railroad, New York, 1908.
Pennsylvania Railroad, New Jersey, New York, Long Island, 1910.
Michigan Central Railroad, Detroit and Windsor, 1910.

Congestion of traffic at terminals, where freight is transferred from one line to another, always presents a serious situation. Delays are caused by "protection" inspection at the point of interchange, and also by steam motive power which is unwieldy. The cost of the motive power at terminals is also high due to the nature of the operation of the boiler and engine in common switching locomotives.

New York Dock Commission completed plans in 1910 for the establishment of a $100,000,000 electric railway freight terminal near the North River in Manhattan; the New York Central in 1911 announced its determination to use electric traction for its freight terminals.

Massachusetts Railroad Commission has recommended the electrification of all the railroads at the Boston terminal, stating:

"The number of tracks in stations is limited. The cutting of the 3-minute headway between steam trains to 2-minute, with electric service, would increase the terminal capacity of the Boston Station 50 per cent. by decreasing switching, increasing acceleration, and more rapid movements."

Buffalo terminals should be electrified by the several railroads, according to a comprehensive report made in 1908 by the Buffalo Commercial Club. The city council by ordinance has required all the railroads within the city to electrify their lines prior to 1913.

Montreal, Toronto, Cleveland, Cincinnati, Chicago, and St. Louis are now considering electric power for railroad terminals.

Terminal electrification is always carried out with improvements in track elevation or depression, added terminal sidings, rearrangement and reconstruction, block signaling, etc., which items frequently represent a greater expenditure than the electrification of the terminal.

Railroads have found that electricity can meet all physical and mechanical demands for terminals. Transportation problems, however, are far reaching, the amount of money involved is large and often hard to get, and established conceptions are persistently adhered to. Argument for electric traction are now based on economic considerations to win adequate recognition.

## SWITCHING YARDS.

Many steam railroads in freight districts of our cities have now been equipped with electric locomotives. However, many of the installations noted in the last table, "Railroads using Electric Traction at Terminals," were in the vicinity of good resident districts. Further, good resident districts grew up around these railroad yards after electric traction abolished the exhaust steam noise and the smoke nuisance. Hundreds of such cases might be cited, and the agitation for more of this work is evident in every large city. Switching of short and long freight trains is now performed economically and effectively with electric locomotives. Some of the American railways using electric switching locomotives for common switching yards are listed:

Havana Central Railway, 1906.
Shawinigan Falls Terminal Ry., 1908.
Montreal Terminal Railway, 1908.
Claremont (N. H.) Railway, 1908.
Bush Terminal Ry., Brooklyn, 1904.
Hoboken Shore Railway, N. J., 1898.
Brooklyn Rapid Transit, 1907.
Nashville Interurban Railway, 1909.
Chicago & Milwaukee Electric Ry., 1898.
Illinois Traction Company, 1900.
Kansas City & Westport, 1902.
Portland (Ore.) Railway, 1904.
Gallatin Valley Ry., Montana, 1910.
New York, New Haven & Hartford, 1911, Harlem River and New Rochelle Yards.
Pennsylvania, Sunnyside Yards, 1910.

## FREIGHT SERVICE.

Freight service on electric railways is a very recent development. Street railways, from the first, hauled small packages, and often larger commodities, in the vestibule, as an accommodiation, not for profit. Interurban railways carried mail and ordinary express almost from the beginning. The service was appreciated, and the traffic grew. Motor

cars were then given over exclusively to the handling of perishable fruit and meats. Flat cars were often run as trailers, to carry lumber, stone, sand, and construction materials. Motor cars were soon used to carry coal, building, and track material. As the interurban roads grew in length, it was found convenient to use the forward quarter of each passenger car for an express compartment to carry merchandise, trunks, and baggage. In addition to this service, thousands of electric motor cars are now operated exclusively for handling express, freight, and farm commodities. Milk cars are used on the morning and evening runs. Steel baggage cars are now used at the head of many motor-car trains.

Freight haulage on city streets has been objected to, but its convenience was also recognized, and, in some places, the merchants have induced city councils to allow freight traffic at night. Ore from the mines has thus been hauled by electric motors thru the streets of Butte, Montana. Freight haulage became so important after 1900 that electric railways secured a private right-of-way around cities, so that long freight trains could be hauled by electric or steam locomotives. Extensive yards have been built at the outskirts of some cities.

Interurban roads are well adapted and organized for the haulage of coal, building material, grain, and live stock, in car loads, at regular steam-road rates. The investment has already been made in the power house and tracks; and freight equipment may be used, particularly at night, with a very small additional expenditure for organization and power. The freight load, when handled in many trains at night, equalizes the work and increases the economy of the power plant.

Net earnings of many well established interurban lines can neither be increased by a larger passenger business nor by future economies in operation; but the net earnings are now being increased by developing the freight traffic, and the passenger business is being made an advertisement for the freight traffic department.

**The volume of electric interurban freight business is noted.**

Toledo & Western Railroad, with 84 miles of track, hauled 6759 carloads of freight in 1908. The freight rates are the same as for steam roads. The thru freight trains are operated daily in each direction between Toledo and Pioneer, Ohio, and Adrian, Michigan. The company has 22 station agents, operates in 18 towns, and has adopted steam-road, rather than interurban-railway methods in acquiring and conducting its business. Its equipment consists of five 30- to 50-ton electric locomotives, 4 electric express cars, and 93 box, flat, stock, and gondola cars. Operation would be improved if the western terminals were larger. St. Ry. Journ., Sept. 2, 1905, p. 328; Sept. 18, 1909, p. 424; E. T. W., June 18, 1910.

Western Ohio Railway has developed an important fast freight service, and particularly a double daily thru service between Toledo and Dayton, 162 miles.

Ohio Electric Railway has 210 cars in freight service; Indiana Union Traction has 129; and Terre Haute, Indianapolis & Eastern has 134 cars equipped with train brakes and automatic couplers; and has built freight loops around the larger cities.

Illinois Traction Company, on its 600 miles of interurban road, operates 18 express motor cars, 40 express trailers, 30 electric locomotives, 25 grain cars, and 500 coal gondolas of 80,000 pounds capacity. Freight trains carrying high-class freight run in four- to eight-car trains. Coal aggregating 1500 tons is hauled daily. Low-grade commodities are hauled in carload lots. The traffic is largely between St. Louis, Springfield, Peoria, Champaign, and Danville. Thirty cars of package freight are taken in and out of St. Louis daily. The service between these points is so much quicker than that given by steam roads that it competes successfully even when the steam roads have the short-line mileage. The freight traffic is, for the most part, confined to localized business, centering around the larger cities, for which it receives a higher rate (1.2 cents) per ton-mile or double that for thru shipments.

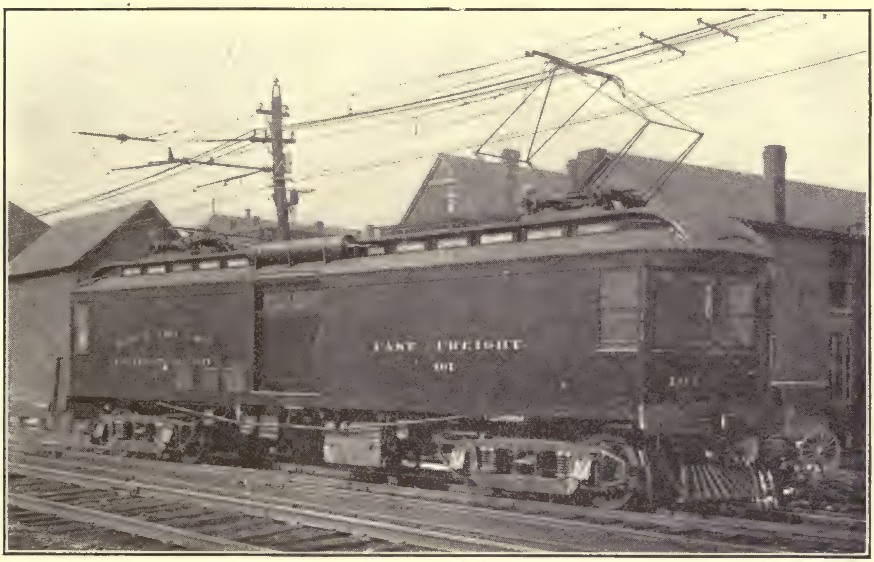

FIG. 8.—ROCK ISLAND SOUTHERN RAILWAY EXPRESS CAR.

Freight loops have been built around Decatur, Springfield, and Edwardsville, Ill. The freight terminal at St. Louis covers 24 acres of land.

Joint traffic agreements exist between this company and the Chicago & Eastern Illinois, and other intersecting steam roads. Foreign cars are handled on the usual per diem basis, under M. C. B. rules, and the company is allowed the same division of the rates as a steam road similarly situated, the originating or delivering road receiving at least 25 per cent. of the total freight charges.

This road now handles 3,000,000 tons of freight, and the revenues therefrom are \$500,000 per annum, or 20 per cent. of its gross earnings. This represents new business. The road is an important feeder and distributor for the steam roads.

Spokane & Inland Empire R. R., with 500 freight cars, and 242 miles of road, uses six 52-ton and eight 72-ton locomotives to haul 300-ton freight trains over heavy grades.

Puget Sound Electric Railway handles 20 cars of coal per day on a 12-mile haul from Renton. Its freight earnings are about \$175,000 per year. Its freight equipment consists of 12 express motor cars, 286 hopper, flat, and gondola cars.

Portland Railway L. & P. Co. has 8 electric locomotives and 353 freight cars.

Oregon Electric Railway has 100 freight cars and two 50-ton electric locomotives for general freight haulage. It has established, from any point on its 70 miles of line, eastbound transcontinental freight rates to all eastern common points in connection with the Spokane, Portland & Seattle Railroad and the Southern Pacific. The basis is 10 cents per 100 pounds arbitrary over Portland. E. T. W., May 14, 1910.

Northern Electric Railway of California has 6 electric locomotives and 600 freight cars. Its 1910 freight revenue was $139,860 or 27 per cent. of its total.

Pacific Electric Railway, of Los Angeles, Cal., with 600 miles of track, has freight agencies in 32 cities and towns. The bulk of the business is local freight for points within 40 miles of Los Angeles, and averages 250 car loads each way per day. The rates average 8/10 cents per ton-mile for less than car loads, and 5/10 cents per ton-mile for car loads. The company has a double-track, private right-of-way into the city. Trains are composed of from 4 to 25 cars. Express motor-cars are used for the bulk of the work, and some of these motor-cars are equipped to handle 10 trailing cars; but heavier trains are hauled by electric locomotives. Car-load business is transferred from private sidings and shipping houses and other points, on the city streets, at night. The freight equipment includes 18 electric locomotives, each of 350 h. p.; 20 freight motor cars rated 300 h.p., each hauling 10 loaded cars; 600 box and other freight cars, and 300 steel freight cars of 100,000-pound capacity. Its freight revenue in 1910 was $444,564 or 9 per cent of its total revenue.

**Express business** is usually conducted by national express companies. U. S. Express Company and Southern Ohio Express Company handle the express business for the principal electric railways of Ohio and Indiana, their contracts covering 2600 miles. In all, they now operate on 6000 miles of electric railway route in the United States. Basis of agreement is usually 50 per cent. of the gross earnings, or 25 cents per cwt. for local hauls, and a definite guarantee per mile per year, to the electric railway.

**Interstate Commerce Commission,** in 1908, considered the needs of shippers on different electric lines, and concluded that where there was sufficient traffic the Commission was justified in establishing thru routes and joint thru rates. It therefore required the establishment of such rates. The basis, in general cases, is not more than 10 per cent. of the class and commodity rate of the steam railroads between distant points and common points on the electric line, for the transportation of interstate traffic. Prior to this time, the steam railroads contended that the electric railway companies legally were not railroads, and, because they could not reciprocate with exchange equipment, the steam railroads were not benefited by such interchange of traffic and joint rates. Interstate Commerce Commission decided that the needs of the shipper could not thus be set aside. In March, 1911, the Commission ordered the steam roads to supply electric roads with switching connections and thru rates. E. R. J., April 8, 1911, p. 637.

Financial advantages of electric haulage of freight are argued in Chapter III. The present status is indicated by the present gross revenue.

ANNUAL FREIGHT REVENUE OF ELECTRIC ROADS.

| Name of railway. | Mileage. | Year noted. | Freight revenue. | P. C. of total. | Per track mile. |
|---|---|---|---|---|---|
| Massachusetts Electric | 932 | 1907 | 49,400 | 0.7 | $ 53. |
| Old Colony | 381 | 1910 | $63,980 | 3.0 | 168. |
| Rhode Island Company | 319 | 1909 | 169,580 | 4.0 | 531. |
| Connecticut Company | 755 | 1908 | 224,292 | 3.0 | 290. |
| Fonda, Johnstown & G.ville | 85 | 1909 | 223,752 | 28.9 | 2632. |
| Schenectady Railway | 133 | 1907 | 46,000 | 4.0 | 347. |
| Hudson Valley Railway | 149 | 1908 | 127,000 | 19.0 | 852. |
| Toronto & York Radial | 81 | 1909 | 47,316 | 13.4 | 584. |
| Buffalo & Lockport Ry | 25 | 1908 | 98,251 | ........ | 3930. |
| Utica & Mohawk Valley Ry | 114 | 1908 | 115,638 | 10.0 | 1014. |
| Albany Southern R. R | 58 | 1907 | 57,948 | 21.0 | 1000. |
| Lackawanna & Wyoming Valley | 50 | 1909 | 52,164 | 9.4 | 1043. |
| Grand Rapids, Holland & Chi. | 81 | 1909 | 56,000 | 20.9 | 691. |
| Grand Rapids, Grand Haven & M. | 49 | 1909 | 56,000 | 20.6 | 1143. |
| Lake Shore Electric | 215 | 1909 | 58,596 | 6.3 | 272. |
| Cleveland, Southwest & Colum. | 213 | 1908 | 62,000 | 8.0 | 291. |
| Eastern Ohio Traction | 95 | 1909 | 73,621 | 28.8 | 775. |
| Ohio Electric Ry | 850 | 1909 | 207,553 | 8.6 | 244. |
| Toledo Urban & Interurban | 71 | 1908 | 28,000 | 8.0 | 400. |
| Western Ohio Ry | 112 | 1909 | 54,823 | 13.8 | 489. |
| Toledo, Port Clinton & Lakes | 55 | 1909 | 23,281 | 13.1 | 423. |
| Cincinnati Interurban Ry. & T. | 116 | 1909 | 52,378 | 23.3 | 451. |
| Scioto Valley Traction | 78 | 1910 | 50,934 | 13.6 | 653. |
| Toledo & Western | 80 | 1909 | 81,000 | 31.2 | 1012. |
| Dayton & Troy Electric | 49 | 1909 | 26,777 | 10.3 | 546. |
| Indiana Union Traction | 365 | 1909 | 181,168 | ........ | 496. |
| Indiana, Columbus & Southern | 65 | 1908 | 20,000 | 7.0 | 309. |
| Cincinnati, Georgetown & P. | 57 | 1909 | 56,365 | 28.0 | 989. |
| Toledo & Indiana | 56 | 1909 | 34,651 | 18.2 | 619. |
| Fort Wayne & Wabash Valley | 212 | 1909 | 56,706 | 3.1 | 267. |
| Indianapolis & Cincinnati | 116 | 1909 | 44,213 | 23.0 | 381. |
| Terre Haute, Indiana & Eastern | 400 | 1909 | 180,662 | 7.8 | 451. |
| Illinois Traction | 530 | 1909 | 400,000 | 20.6 | 755. |
| East St. Louis & Suburban | 181 | 1908 | 63,619 | 7.0 | 351. |
| Chicago & Milwaukee Electric | 186 | 1909 | 58,855 | 8.0 | 300. |
| Milwaukee Northern Ry | 64 | 1909 | 16,772 | 7.0 | 262. |
| Waterloo, C. F. & Northern | 100 | 1909 | 90,226 | 35.9 | 902. |
| Portland Ry. Light and Power | 472 | 1909 | 153,631 | 22.3 | 325. |
| Puget Sound Electric | 200 | 1909 | 143,686 | 7.7 | 718. |
| Spokane & Inland Empire | 201 | 1910 | 472,918 | 27.7 | 2362. |
| Los Angeles—Pacific | 260 | 1910 | 207,778 | 12.2 | 799. |
| Electric Ry., Canada | 988 | 1909 | 575,000 | 3.1 | 572. |
| Electric Ry., United States | 34,405 | 1907 | 7,438,582 | 2.0 | 216. |
| Steam R. R., United States | 327,975 | 1907 | 1,936,000,000 | 74.5 | 5903. |

The freight revenues of electric roads doubled between 1902 and 1907, and are now increasing at a rapid rate.

References on Interurban Freight Traffic: U. S. Census Report, 1907, pp. 92 and 138; annual reports of railway companies; Elec. Ry. Journ., July 11, 1908, Oct., 10, 1908; pp. 824 and 1069; Oct. 8, 1910, p. 610.

FREIGHT REVENUE OF ELECTRIC ROADS.

Last Report of State Railroad Commission.

| State. | Miles of road. | Passenger earnings. | Freight earnings. | Freight per cent. |
|---|---|---|---|---|
| Rhode Island | 393 | $5,284,716 | $157,351 | 3.0 |
| Massachusetts | | | 175,000 | |
| Indiana | | 9,538,776 | 700,000 | 7.6 |
| Ohio | 2794 | 11,000,000 | 910,000 | 8.3 |
| Michigan | | 10,458,000 | 533,329 | 5.3 |
| Illinois | 1303 | 13,350,000 | 426,000 | 3.2 |

**Railroads use electric locomotives for freight haulage** in regular service notably on the Baltimore & Ohio since 1895; Hoboken Shore Line, 1898; Buffalo & Lockport, 1898; Paris-Orleans, 1900; St. Louis & Belleville, 1901; Cincinnati, Georgetown & Portsmouth, 1903; Grand Trunk, 1908; New York, New Haven & Hartford, 1910; Michigan Central, 1910.

In America, about 310 electric locomotives are now used for freight haulage.

In England, North-Eastern Railway, has used six 55-ton electric locomotives and also multiple-unit cars for freight and express service since 1904. The cars are 55 feet long, have four 125-h.p. motors, and handle luggage, parcels, and fish; and they are coupled to either an electric or a steam-driven train.

### ELECTRIC LOCOMOTIVES.

A brief history of electric locomotives is presented:

In 1880, Edison ran a number of experimental locomotives at Menlo Park with power from a dynamo. The 1880 locomotive is now at Brooklyn Polytechnic Institute. In 1882, Henry Villard, President of the Northern Pacific R. R., contracted for an electric locomotive for freight service in the Dakotas. It was equipped by Edison with a series belted 220-volt, 10-h. p. motor and hauled three-car trains, power being supplied thru the two track rails. Hammer, in Elec. World, June 10, 1899, and Elec. Review, July 23, 1910, gives photos, drawings, and maps.

In 1883, Edison, Field, Mailloux, and Rea operated a geared and belted 3-ton electric locomotive, "The Judge," using a third-rail contact line, over 1550 feet of track at the Chicago Railway Exposition and at the Louisville Exposition. A Weston dynamo and motor were used. St. Ry. Journ., March 5, 1904, p. 451; December 10, 1904, p. 1035.

In 1883, Daft ran a successful small standard-gage locomotive

Fig. 9.—Edison Electric Locomotive, 1880.
Positive and negative rails; armature belted to axle.

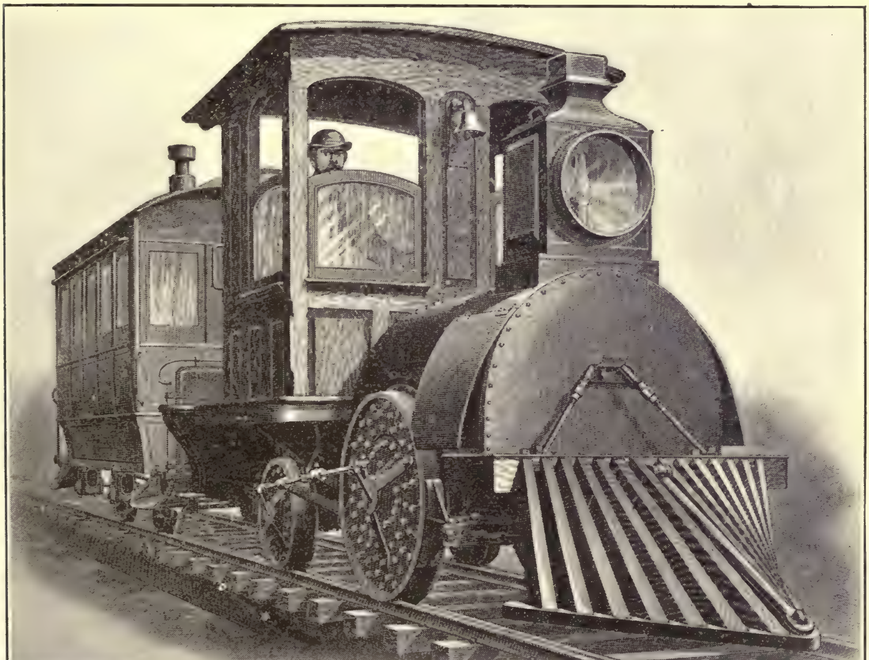

Fig. 10.—Improved Edison Electric Locomotive, 1882.
A steam locomotive designer had been employed.

between Mt. McGregor and Saratoga, N. Y., 12 miles, and hauled a regular 10-ton steam passenger car. A double-belted, 130-volt, 15-h.p. motor with countershafts was used, and a third rail.

In 1884, Daft operated locomotives and coaches, in experimental work, on a 2-mile road between Baltimore and Hampden. The motors on two electric locomotives were a 130-volt, direct-current type. The gearing used was single-reduction, with cut steel pinions and cut cast-iron gears. The third rail was used, also an underground trolley. Horatio A. Foster installed the equipment. Elec. World, March 5, 1904. See Fig. 2.

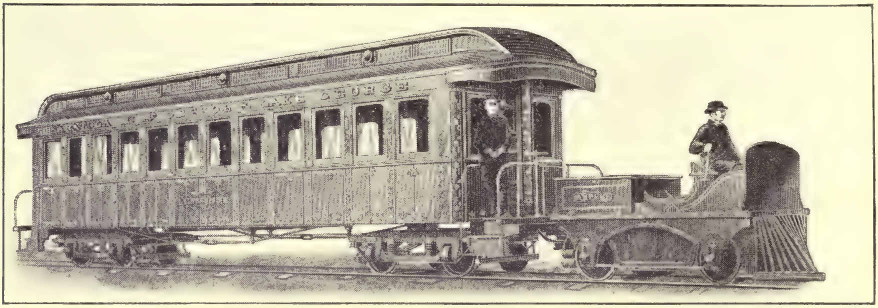

Fig. 11.—Daft Electric Locomotive "Ampere". Saratoga, Mt. McGregor and Lake George Railroad, 1883.

In 1885, Daft developed a 2-mile, third-rail line for the Ninth Avenue Elevated, New York, from Fourteenth to Fiftieth Streets. A 10-ton, 4-wheel locomotive was equipped with a 75-h. p., single-reduction, 450-volt motor. The truck had two 48-inch drivers and two 33-inch trailer wheels. Four-car trains were hauled at night experimentally, for a long period. The locomotive called the "Franklin" was re-equipped in 1888 with 4-coupled drivers and a 125-h. p. motor and hauled an 8-car train at 10 miles per hour. The "Franklin" avoided the use of belts, gears, and cranks, power being transmitted by friction from wheels on the armature to wheels on the axle. The armature shaft carried a 9-inch diameter friction wheel, with a 4-inch ground face, which bore down upon a 36-inch friction wheel, keyed to the axle of the drivers. The friction was varied by means of screw pressure. See Martin and Wetzler, "The Electric Motor," second edition, p. 79, for drawings; St. Ry. Journ., Oct. 8, 1904, p. 529; A. I. E. E., June, 1899.

In 1888, Johnston, Sprague, Hutchinson, and Field designed and operated a heavy experimental side-rod locomotive on the Second Avenue line and Thirty-fourth Street branch line of the New York Elevated Road. Martin and Wetzler, "The Electric Motor," 2d Edition, 1888, p. 204.

In 1890, City and South London began the use of Mather and Platt, single-truck, 15-ton gearless locomotives in its 11-foot diameter tube railways, each locomotive hauling three 8-ton coaches. There are now 58 locomotives, and they are in heavier service.

In 1893, Chicago Columbian Exposition exhibited a General Electric 30-ton, 4-wheel freight locomotive.

Length was 16 feet, wheel base 66 inches, drivers 44 inches. Motors were 240-h. p. 500-volt units, supported on spiral springs resting on the locomotive truck frames. Armatures were iron-clad, gearless, quill-mounted, and connected to axles by flexible couplings. Series-parallel controllers were used. At 30 m. p. h., the rated drawbar pull was 6000 lbs. Maximum drawbar pull was 13,000 lbs. In tug with a steam locomotive having a greater weight on drivers, the electric locomotive showed the greater tractive effort. Description and photo in Electrical Engineer, July 12, 1893.

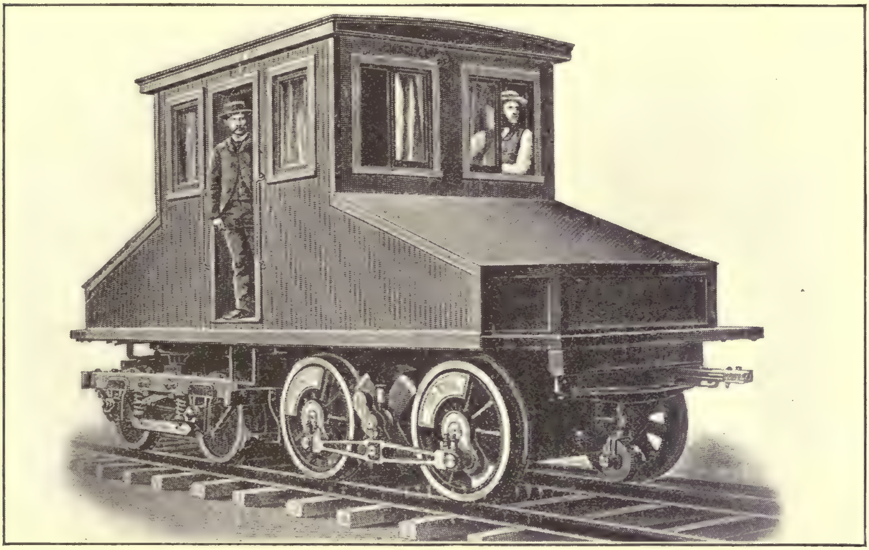

Fig. 12.—Electric Locomotive. S. D. Field, 1888.
The armature was crank-connected to the side rod. Motor was spring mounted on the truck. Weight 13 tons; drivers 42-inch. Direct current at 800 volts. Third rail.

In 1893, the North American Co., Henry Villard, president, had a locomotive built by the Baldwin and the Westinghouse companies, under the supervision of Messrs. Sprague, Duncan, and Hutchinson, for experimental work in freight hauling and switching at Chicago.

The locomotive weighed 60 tons. There were four sets of 56-inch coupled drivers. The rigid wheel base was 15 feet. The connection between the armature shaft and the drivers was by means of gearing. Motors used were four 200-h. p. Westinghouse, iron-clad type, 225 r. p. m., direct-current, 800-volt, 250-ampere units. Series-parallel control was used. Magnets were compound wound, but the shunt field had only sufficient turns to keep the speed within reasonable limits at light loads. The motors were designed to return current to the line when running down grades. See drawings and descriptions in Electrical Engineer, July 12, 1893; Oct. 8., 1893, p. 339; Baldwin-Westinghouse publication, "Electric Locomotives," 1896; Elec. World, March 5, 1904

In 1895, Baltimore & Ohio Railroad began the use of five 96-ton. 1040-h.p. electric locomotives for hauling all ordinary passenger and freight trains thru its Baltimore Belt Line tunnel and terminal. These are still in active service and seven freight locomotives have been added. The steam railroad field was practically uninvaded until this date.

In 1898, Buffalo & Lockport Railway began the use of two 640-h. p. locomotives for the haulage of ordinary freight, in 8- to 12-car trains, between Tonawanda and Lockport, N. Y. They are still in active service.

In 1900, St. Louis & Belleville Electric Railway, a pioneer electric freight road, began the use of two 50-ton locomotives. For ten years, 720-ton, 16-car coal trains have been hauled in regular service.

Fig. 13.—St. Louis and Belleville Electric Railway.
Fifty-ton locomotive and ordinary 720-ton coal train.

In 1900, Central London Railway, an underground tube road, installed 40 locomotives each equipped with 4 GE-56, gearless, direct-current, 170-h.p. motors. The armature core was built directly on the axle. The locomotive weighed 48 tons, about 13 tons spring-bourne and 35 tons not spring-bourne. The rigid construction of these locomotives shook and damaged the buildings above. They were superseded by locomotives equipped with 4 GE-55, geared, 150-h.p., motors. The gear ratio was 3.3 and the weight was 34 tons. There was still some vibration, and the locomotives were abandoned for 7-car motor-car trains with 500 h. p. per train. St. Ry. Journ., Oct. 11, 1902; Nov. 7,1903.

Mr. W. J. Clark, in the U. S. Census Report on Street and Electric Railways of 1907, has listed 558 steam locomotives on 126 roads which were replaced by electric units on electric railways; also 863 additional steam locomotives which were replaced by electrical equipment on 24 steam railroads. Many steam locomotives have since been discarded.

"Electric Locomotives" form the subject of succeeding chapters.

### ELECTRIC TRACTION BY ELECTRIC RAILWAYS.

Electric traction by electric railways *for ordinary service* forms one step in the advance in the art of transportation. Electric power was first used for freight and passenger service by roads which were *not* formerly steam railroads, but which were organized to build and operate *new* railways with electric motive power. The best first examples of the American roads are listed.

| | |
|---|---|
| Albany & Hudson R. R. | Buffalo & Lockport Railway. |
| Lake Shore Electric Railway. | Lackawanna & Wyoming Valley R. R. |
| Scioto Valley Traction Co. | Indiana Union Traction Co. |
| Terre Haute, Indianapolis & East. | Ohio Electric Railway. |
| Aurora, Elgin & Chicago R. R. | Chicago & Milwaukee Electric R. R. |
| East St. Louis & Suburban Ry. | Illinois Traction Co. |
| Puget Sound Electric Railway. | Spokane & Inland Empire R. R. |

### ELECTRIC TRACTION BY STEAM RAILROADS.

Electric traction was first used by steam railroads for special situations. Physical and financial advantages were gained. Many of the special situations have been listed, viz:

Prevention of competition.

Elevated lines, subways, and tunnels.

Mountain grade lines for heaviest service.

Terminal railways, with congested traffic.

Freight service for local railways.

Utilization of water power. See "Power Plants."

Electric locomotives for terminals, switching yards, factory service.

Motor-car trains in place of steam locomotive-hauled trains, for heaviest rapid transit and suburban railway passenger service.

Change in motive power to improve a bad financial situation, to regain traffic and to reduce expenses. This is considered in "Advantages of Electric Traction," and in "Procedure in Railroad Electrification."

### ELECTRIC TRACTION IN GENERAL USE FOR TRAINS.

Electric traction now receives consideration for economic reasons, and for passenger and freight train service, by electric railway corporations and by steam railroad corporations.

This is the work of the present and future. The tendency at present is to systematically consolidate the electric railways, to increase the long runs, to run two-car trains in place of long single cars, to obtain better management, to effect economies, and to standardize. Great savings are being effected as railways are brought under one financial and engineering management. Thru electric-train service between the leading cities,

St. Louis, Springfield, Terre Haute, Indianapolis, Chicago, Cincinnati, Cleveland, Buffalo, Albany, Boston, New York, and Washington, is being developed by interurban railways; and this will be followed by the electrification of trunk lines.

Steam railroads electrify their lines for economy of operation and to regain lost traffic. It is a noticeable fact, frequently impressed, that as the steam railroads electrify, the work is of a most substantial character.

Electric power will first be adopted, to the financial advantage of the public and of the steam railroad, in zones around our great cities: Boston, New Haven, New York, Philadelphia, Washington, Baltimore, Pittsburg, Albany, Buffalo, Montreal, Toronto, Chicago, Rock Island, Minneapolis and St. Paul, St. Louis, San Francisco, and Los Angeles. Co-operative plans for the generation of electricity will effect large savings in capital. Water powers of the Cascade, Rocky, and Sierra Nevada Mountains will be used by railroad corporations to haul their electric trains, at first near Denver, Salt Lake, Spokane, Seattle, and in the Columbia and Sacramento River Valleys. Passenger trains will use electric traction first, but for economy freight haulage must be added.

In the early days, 1860, passenger traffic produced the larger part of the earnings of steam railroads, but the freight earnings soon exceed the passenger earnings. The freight earnings of electric railroads will, likewise, soon exceed the passenger earnings, both in amount and in profit.

The history of steam railroads shows that there was at first no idea of interchange of traffic, involving the use of cars and locomotives; but that in 1878 a standard gage for track, interchangeable (M. C. B.) couplers, brakes, heating pipes, and signals, were adopted. Likewise, electric railroads are now being systematized so that coaches, coupled as in ordinary railroad trains, will have automatic brakes, standard heating apparatus, etc. Electric trunk-line roads must standardize, and use interchangeable electric systems, voltage, cycles, and phase, so that direct-current and alternating-current service may be used for any train.

Regarding the work done, an index, in the first part of Chapter XV, of all steam railroads using electric traction for trains, shows that not one per cent. of the total mileage has yet been electrified.

Electric power has economic advantages which are being utilized to *improve* transportation methods. The idea is not merely to supersede steam-locomotive traction, but rather it is to assist in producing efficient transportation by new methods.

The importance of electric railway transportation in the United States may be shown by statistics; and when these are compared with other statistics they show that the capital invested and the gross earnings of electric railways are more than twice as large as those for all other public electric utilities combined.

EARNINGS AND MILEAGE OF RAILWAYS OPERATING ELECTRIC TRAINS.

| Name of electric railway. | Gross earnings 1908. | Gross earnings 1909. | Gross earnings 1910. | Elec. mileage 1911. |
|---|---|---|---|---|
| Boston Elevated | $14,074,696 | $14,993,853 | .......... | 485 |
| Massachusetts Electric | 7,809,010 | 8,052,355 | 8,560,949 | 934 |
| The Rhode Island Company | 4,217,022 | 4,192,958 | 4,502,922 | 319 |
| The Connecticut Company | 6,961,436 | 6,841,425 | 7,235,729 | 780 |
| Interboro Rapid Transit | 25,279,470 | 27,160,036 | 28,987,648 | 85 |
| Long Island R. R. | 9,818,544 | 10,898,371 | 9,779,116 | 263 |
| Hudson & Manhattan R. R. | .......... | 743,701 | 2,237,459 | 18 |
| Albany Southern R. R | 267,777 | .......... | 480,062 | 62 |
| Fonda, Johnstown & Gloversville | 809,925 | 773,849 | 904,751 | 85 |
| Utica & Mohawk Valley | 1,151,031 | 1,193,806 | 1,257,621 | 127 |
| Rochester, Syracuse & Eastern | 310,958 | 382,037 | 503,218 | 168 |
| Windsor, Essex & Lake Shore | 35,585 | 85,273 | 106,225 | 40 |
| Lackawanna & Wyoming Valley | 524,509 | 555,402 | 576,029 | 50 |
| Michigan United Rys | 573,439 | 1,026,796 | 1,248,889 | 254 |
| Cleveland, Southwestern & Colum. | 775,737 | 827,898 | 955,591 | 243 |
| Northern Ohio Traction | 1,890,473 | 2,177,642 | 2,437,426 | 214 |
| Mahoning & Shenango | 1,747,927 | 1,966,066 | 2,251,482 | 149 |
| Eastern Ohio Traction | 259,172 | 270,759 | .......... | 94 |
| Toledo & Western | 236,538 | .......... | 301,618 | 84 |
| Western Ohio | 441,791 | 490,328 | 558,374 | 112 |
| Scioto Valley Traction | 355,000 | 383,053 | 422,914 | 79 |
| Fort Wayne & Wabash Valley | 1,322,720 | 1,414,526 | 1,526,587 | 212 |
| Indiana Union Traction | 1,902,330 | 2,103,018 | 2,364,628 | 373 |
| Indianapolis, Columbus & Southern | 344,694 | 385,424 | 418,287 | 59 |
| Indianapolis & Cincinnati Traction | 200,355 | 214,990 | 448,099 | 112 |
| Cincinnati, Georgie. & Portsmouth | 164,493 | 167,514 | 174,530 | 57 |
| South Side Elevated R. R | 2,214,690 | 2,234,973 | 2,457,489 | 46 |
| Metropolitan West Side Elevated | 2,746,840 | 2,818,430 | 3,069,945 | 57 |
| Chicago & Oak Park Elevated | 869,892 | 825,453 | 840,378 | 20 |
| Northwestern Elevated R. R | 2,463,188 | 2,540,883 | 2,632,039 | 51 |
| Aurora, Elgin & Chicago | 1,408,892 | 1,467,215 | 1,608,438 | 160 |
| Illinois Traction Co | 4,089,621 | 4,752,082 | 6,106,250 | 550 |
| East St. Louis & Suburban | 2,009,514 | 2,035,790 | 2,364,142 | 181 |
| Chicago & Milwaukee Electric | 597,977 | 921,019 | 945,152 | 166 |
| Milwaukee Northern | .......... | 85,444 | 287,848 | 64 |
| Rock Island Southern | 76,191 | 91,438 | .......... | 82 |
| Fort Dodge, Des Moines & Southern | .......... | 432,540 | 450,747 | 140 |
| Waterloo, Cedar Falls & Northern | 217,103 | 251,834 | 234,072 | 90 |
| Northern Texas Traction | 1,080,577 | 1,259,551 | 1,442,807 | 82 |
| Spokane & Inland Empire | 1,146,177 | 1,269,100 | 1,763,614 | 287 |
| Puget Sound Electric | 1,694,973 | 1,869,096 | 1,915,289 | 200 |
| Oregon Electric | .......... | .......... | 554,819 | 80 |
| Northern Electric | .......... | 422,901 | 512,992 | 138 |

STEAM AND ELECTRIC RAILWAY STATISTICS SUMMARIZED.

| Statistics from government reports | Steam railroads 1907. | Electric railways 1907. | Ratio electric to steam. |
|---|---|---|---|
| Passengers carried | 873,905,133 | 9,533,080,766 | 10.900 |
| Rides per inhabitant per year | 9 | 90 | 10.000 |
| Total car mileage | 29,652,000,000 | 1,618,343,584 | .054 |
| Receipts from passengers | $564,606,342 | $382,132,494 | .677 |
| Income from freight | 1,936,000,000 | 7,438,582 | .004 |
| Income from operation | 2,649,731,911 | 429,744,254 | .162 |
| Operating expenses | 1,749,164,649 | 251,309,252 | .143 |
| Net earnings | 900,567,262 | 178,435,002 | .200 |
| Taxes and fixed charges | 420,717,658 | 138,094,716 | .325 |
| Net income | 479,849,604 | 40,343,286 | .084 |
| Dividends | 227,394,962 | 25,558,857 | .113 |
| Surplus | 252,454,642 | 14,781,429 | .059 |
| Capitalization, at par | 18,885,000,000 | 3,774,000,000 | .200 |
| Total mileage | 327,975 | 34,404[1] | .105 |
| Passenger cars | 43,973 | 70,016 | 1.600 |
| Freight cars, etc | 1,991,557 | 13,625 | .007 |
| Total cars | 2,126,594 | 84,000 | .040 |
| Locomotives | 51,891 | 117[2] | .007 |
| Motor cars | .............. | 68,874 | .......... |
| Horse-power capacity | 5,000,000 | 2,475,000 | .490 |

[1] The mileage of electric railways in 1911 is about 36,000 miles.
[2] The number of electric locomotives in 1911 is about 430.

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# CHAPTER II.

## CHARACTERISTICS OF MODERN STEAM LOCOMOTIVES.

**Outline.**

**Introduction on Railway Practice.**
**Locomotive Classification.**
**Data Sheets on Proportions.**
**Physical Characteristics:**

Self-contained power units, water supply, coal, boilers, center of gravity, wheel base, simple engines, design for service conditions, weight, capacity, heating surface, tractive effort, piston speed, horse power.

**Operating Characteristics:**

Furnace conditions, high rates of evaporation, heat radiation, stand-by losses, weather ratings, operation by enginemen, unbalanced forces, track destruction, friction losses, speed of trains, mechanical strains, locomotive repairs, condensation, superheat, steam consumption, economy of coal.

**Speed-Torque Characteristics:**

Indicator diagrams, short strokes, piston speed, initial steam pressure, losses in pressure, indefinite point of cut-off, clearance, back pressure, expansion of steam, mean-effective steam pressure, relation between speed and torque, work done in cylinders.

**Compound Locomotives.**
**Mallet Locomotives.**
**Turbine Locomotives.**
**Cost of Operation,** fuel, repairs, total.
**Literature.**

# CHAPTER II.

## INTRODUCTION.

Modern steam locomotives in railroad practice to-day are accepted as the approved motive power for the transportation of ordinary trains, because steam traction has certain physical and economic advantages. Where coal is cheap and service is infrequent, the steam locomotives will continue to hold the advantage.

Steam locomotives represent the result of seventy years of crystallized experience, in which much has been learned about design and performance, and this may be used as a foundation for still further advance.

Improvements or changes in the motive power used for railroad trains cannot be entertained until after there is a complete understanding of the physical characteristics and the economic performance of the modern steam locomotive. An intimate knowledge of the good and bad physical features, and of the operating results, is needed. Practical experience in round houses, in service tests, and on dynamometer cars is the most profitable means of collecting the information.

A study will now be made of the furnace and boiler, the limitations in design, the indicator cards, the relation of speed to drawbar pull, the dynamometer records, the result of weather conditions, the effect of railway grades, the effect of underload and overload, and the economic results from ordinary and special locomotives. The nature of the facts is of greatest importance. The data contained in the following pages summarize, for general use and for comparative purposes, some of the essential facts and conditions concerning present-day steam locomotives.

## LOCOMOTIVE CLASSIFICATION.

Locomotive classification is made with reference to the number and arrangement of the wheels. The number of driving wheels of steam locomotives is generally limited to two or three pairs in passenger service and to four pairs in freight service. The number and diameter of side-connected drivers establish the length of the rigid driving-wheel base. Leading wheels are required to ease the shock, to guide the locomotive in the curves, and over variations in track alignment—a two-wheeled leading truck for freight engines, and a four-wheeled leading truck for high-speed passenger engines. A pair of trailing wheels often supports the heavy fire-box.

**Switchers** have 4, 6, 8, or 10 small driving wheels, a rigid truck frame, and are usually without leading or trailing wheels.

**Prairies** have 2 leading truck wheels, 6 large driving wheels, and 2 trailing truck wheels, over which there is a deep and wide fire-box.

This type is common for heavy passenger or fast freight service on prairie divisions.

**Moguls** have 2 leading truck wheels and 6 driving wheels, and they are used for heavy freight service.

**Consolidations** have 2 leading truck wheels and 8 driving wheels, and

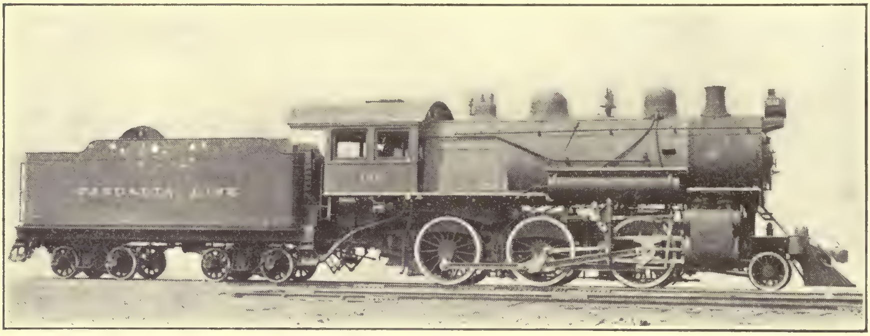

Fig. 14.—Typical Steam Locomotive, Mogul Type.

are a standard for heavy freight service. This type is frequently a 2- or 4-cylinder compound. The wheel base is long. Speeds are not high.

**Decapods** have 2 leading truck wheels and 10 driving wheels giving the maximum wheel base. Few are used.

**Eight-wheeled, or Americans,** have 4 leading truck wheels and 4

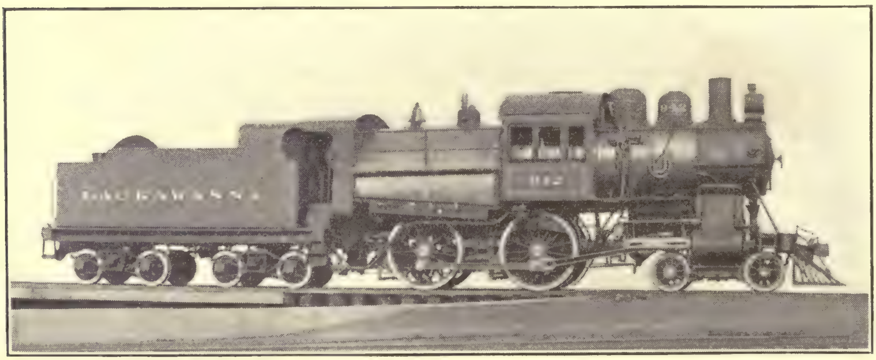

Fig. 15.—Typical Steam Locomotive, Eight-wheel or American Type.

large driving wheels. This is a light-weight, simple locomotive, for ordinary passenger service.

**Ten-wheelers** have 4 leading truck wheels and 6 driving wheels, and are used for both passenger and fast freight service. Twelve-wheelers or mastadons are seldom used.

**Atlantics** have 4 leading truck wheels, 4 driving wheels, and 2 wheels at the grates to carry a large fire-box. This type is used for medium-sized passenger trains, maintaining high speed with few stops.

**Pacifics** have 4 leading wheels, 6 driving wheels, and 2 at the grates, for the heaviest passenger trains.

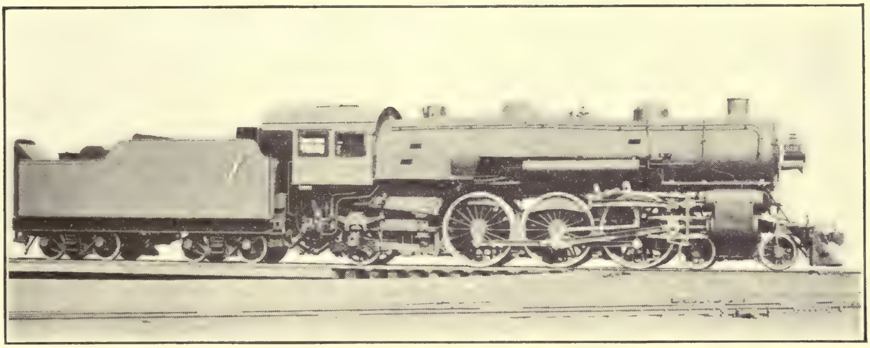

Fig. 16.—Typical Steam Locomotive, Pacific Type.

**Balanced** have Atlantic or Pacific wheel arrangement. The front driver axle is generally a crank axle. A good balance of the reciprocating efforts of the three or four pistons is obtained, and this eliminates most of the hammer blow and allows a greater dead weight per driver axle,


Fig. 17.—Typical Steam Locomotive, Ten-wheel Type.

making it a desirable high-speed passenger locomotive. See page 64.

**Mallet articulated** have 2 sets of cylinders on each side of the locomotive working in compound, articulated or hinged trucks, each with 3 or 4 pairs of driving wheels, generally with leading and sometimes with trailing truck wheels. There is one boiler, rightly attached to the rear truck and supported on the front truck by means of sliding bearings.

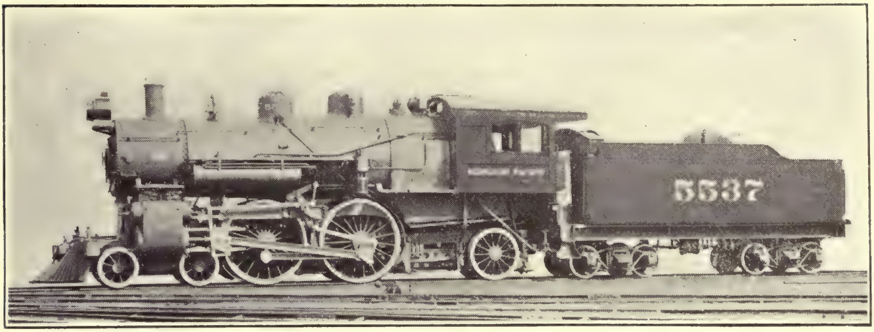


Fig. 18.—Typical Steam Locomotive, Atlantic Type.


Fig. 19.—Typical Steam Locomotive, Prairie Type.


Fig. 20.—Typical Steam Locomotive, Consolidation Type.

## CLASSIFICATION.

Classification of steam locomotives is represented in numerals by the number and arrangement of the pairs of wheels, commencing at the front.

FIG. 21.—TYPICAL STEAM LOCOMOTIVE, MALLET OR ARTICULATED TYPE.
The Delaware & Hudson Company.—Freight service.

### STEAM LOCOMOTIVE CLASSIFICATION.

| Type of Locomotive. | Order of wheels. | No. of wheels. | Wt. on drivers. | Heating surface. | Ordinary service. |
|---|---|---|---|---|---|
| Switcher........ | ∠OOO | 0–6–0 | 100% | 1200–3000 | Local and helper. |
| Prairie.......... | ∠oOOOo | 2–6–2 | 75% | 2000–3800 | Heavy passenger. |
| Mogul........... | ∠oOOO | 2–6–0 | 86% | 2000–2400 | Heavy freight. |
| Consolidation.... | ∠oOOOO | 2–8–0 | 88% | 2200–3600 | Heavy freight. |
| Decapod........ | ∠oOOOOO | 2–10–0 | 90% | 2300–4200 | Heavy freight. |
| American........ | ∠ooOO | 4–4–0 | 65% | 1600–2400 | Light passenger. |
| 10-wheel........ | ∠ooOOO | 4–6–0 | 75% | 2000–2600 | Passenger and freight. |
| Atlantic......... | ∠ooOOo | 4–4–2 | 55% | 2600–3300 | High-speed passenger. |
| Pacific.......... | ∠ooOOOo | 4–6–2 | 60% | 3000–3800 | Heaviest passenger. |
| Balanced........ | ∠ooOOo | 4–4–2 | 57% | 2700–3400 | High-speed passenger. |
| Mallet.......... | ∠oOOO-OOO | 2–6–6–0 | 90% | 3300–7800 | Mountain freight. |

The data are from various sources. Some from a paper by L. H. Fry, before the New York Railroad Club, with which the data on more recent installations have been averaged, and some from the American and Baldwin locomotive catalogues.

### STEAM LOCOMOTIVES USED IN THE UNITED STATES.

Reports of Interstate Commerce Commission, June 30, 1907, 1908, 1909.

| Service. | 1907. | 1908. | 1909. | Cylinder. | 1907. | 1908. | 1909. |
|---|---|---|---|---|---|---|---|
| Passenger..... | 12,814 | 13,205 | 13,317 | Single-expansion.......... | 51,891 | 54,230 | 54,835 |
| Freight....... | 32,079 | 33,840 | 33,935 | Four-cylinder compound... | 1,727 | 1,714 | 1,603 |
| Switching.... | 9,258 | 9,529 | 9,695 | Two-cylinder compound ... | 945 | 923 | 888 |
| Unclassified.. | 1,237 | 1,124 | 1,123 | Unclassified............... | 825 | 831 | 744 |
| Total....... | 55,388 | 57,698 | 58,070 | | 55,388 | 57,698 | 58,070 |

| Locomotive type. | Single expansion. | | | Four-cylinder compound. | | | Two-cylinder compound. | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1907. | 1908. | 1909. | 1907. | 1908. | 1909. | 1907. | 1908. | 1909. |
| Switcher..... | 7,703 | 8,108 | 8,335 | 3 | 6 | 9 | 22 | 22 | 22 |
| Prairie....... | 990 | 1,152 | 1,082 | 222 | 254 | 255 | 36 | 36 | 36 |
| Mogul....... | 5,333 | 5,510 | 5,502 | 142 | 130 | 99 | 181 | 178 | 157 |
| Consolidation. | 15,025 | 15,987 | 16,311 | 422 | 352 | 301 | 394 | 387 | 379 |
| Decapod..... | 17 | 17 | 36 | ........ | 4 | 4 | ........ | ........ | ....... |
| 8-wheel..... | 10,041 | 9,718 | 9,401 | 8 | 10 | 5 | 4 | ........ | ........ |
| 10-wheel..... | 9,666 | 10,202 | 10,067 | 374 | 348 | 336 | 256 | 251 | 249 |
| 12-wheel..... | 613 | 708 | 1,003 | 6 | 2 | 1 | 51 | 49 | 43 |
| Atlantic...... | 1,401 | 1,490 | 1,530 | 262 | 262 | 272 | ........ | ........ | ........ |
| Pacific....... | 640 | 789 | 1,069 | 47 | 47 | 47 | ........ | ........ | ........ |
| Balanced .... | 53 | 57 | 52 | ........ | ........ | ........ | ........ | ........ | ........ |
| Other types.. | 409 | 492 | 447 | 241 | 299 | 274 | 1 | 0 | 2 |
| Total...... | 51,891 | 54,230 | 54,835 | 1,727 | 1,714 | 1,603 | 945 | 923 | 888 |

On an average, about 3000 locomotives or 5 per cent., are added per year. Changes from one type to another show the appreciation of certain types.

## DATA SHEETS ON PROPORTIONS.

### PROPORTIONS OF MODERN STEAM LOCOMOTIVES.

Weights, Lengths, Heating Surface.

| Locomotive Classification. | Weight in tons. | | | Wheel base in feet. | | | Tons per axle. | Tons per foot. | | | Heat. surf. sq. ft. | H.P. per ton. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Driv. | Eng. | Total. | Driv. | Eng. | Total. | | Driv. base. | Eng. base. | Loco. base. | | |
| Switch....... | 77 | 77 | 120 | 11–3 | 11–3 | 40–0 | 25.7 | 6.2 | 6.2 | 3.0 | 2000 | 7.2 |
| Prairie....... | 75 | 100 | 160 | 11–4 | 29–0 | 55–0 | 25.0 | 6.6 | 3.4 | 2.9 | 3000 | 8.0 |
| Mogul....... | 66 | 75 | 130 | 15–0 | 23–3 | 53–0 | 22.0 | 4.3 | 3.2 | 2.4 | 2200 | 7.3 |
| Consolidated. | 84 | 95 | 160 | 16–3 | 24–6 | 55–0 | 21.0 | 5.2 | 3.9 | 2.9 | 3000 | 8.0 |
| American.... | 40 | 65 | 115 | 8–6 | 24–0 | 50–0 | 20.0 | 4.7 | 2.7 | 2.3 | 2000 | 7.5 |
| 10-wheel..... | 65 | 87 | 140 | 14–6 | 26–0 | 54–0 | 21.5 | 4.5 | 2.7 | 2.6 | 2300 | 7.1 |
| Atlantic..... | 52 | 90 | 155 | 7–0 | 27–0 | 58–0 | 26.0 | 7.4 | 3.3 | 2.7 | 3000 | 8.3 |
| Pacific....... | 60 | 100 | 175 | 12–4 | 32–0 | 60–0 | 20.0 | 4.9 | 3.1 | 2.9 | 3300 | 8.1 |
| Balanced.... | 50 | 100 | 170 | 7–0 | 30–0 | 60–0 | 28.0 | 7.1 | 3.3 | 2.8 | 2600 | 7.0 |
| Articulated.. | 150 | 175 | 250 | 10–0 | 45–0 | 83–0 | 25.0 | 7.5 | 3.9 | 3.0 | 5585 | 9.6 |
| ........... | 200 | 230 | 350 | 16–6 | 52–0 | 100–0 | 25.0 | 6.1 | 4.4 | 3.5 | 7000 | 8.6 |

Data are from Sinclair's "Twentieth Century Locomotive"; McClellan's article to A. I. E. E., June, 1905, p. 565; L. H. Fry's New York R. R. Club paper of Sept., 1903; catalogues of American and Baldwin locomotives.

Average and ordinary units are considered. Maximum tons per driver axle frequently exceed 32, in large locomotives; average tons per driver axle are 30 per cent. greater than European practice.

See comparable table under Electric Locomotive Design.

GREAT NORTHERN RAILWAY STEAM LOCOMOTIVE DATA.

| Locomotive type. | Letter. | Wheel arrange. | Heating surface. | Diam. driv. | Cylinders. dimensions | Wt. per axle. | Locomotive Wt. | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Engine. | Total. |
| Mallet .... | L2 | 2–6–6–2 | 3914 | 55 | 20&31x30 | 41,667 | 288,000 | 451,000 |
| Mallet .... | L1 | 2–6–6–2 | 5700 | 55 | 21½&33x32 | 52,667 | 355,000 | 503,000 |
| Atlantic... | K1 | 4–4–2 | 3488 | 73 | 15&25x26 | 50,000 | 208,000 | 356,000 |
| Prairie .... | J1 | 2–6–2 | 3488 | 69 | 22x30 | 53,000 | 209,000 | 357,000 |
| Pacific .... | H3 | 4–6–2 | 3058 | 69 | 25x30 | 53,000 | 227,000 | 375,000 |
| Pacific .... | H2 | 4–6–2 | 3931 | 69 | 22x30 | 53,000 | 227,000 | 375,000 |
| Pacific .... | H1 | 4–6–2 | 3466 | 73 | 21x28 | 54,000 | 207,000 | 346,000 |
| Mastodon.. | G5 | 4–8–0 | 3332 | 55 | 21x34 | 43,000 | 212,000 | 308,000 |
| Mastodon.. | G1 | 4–8–0 | 2307 | 55 | 20x26 | 33,000 | 156,000 | 242,000 |
| Consolidat. | F10 | 2–8–0 | 3340 | 55 | 21x34 | 49,000 | 216,000 | 312,000 |
| Consolidat. | F8 | 2–8–0 | 2767 | 55 | 20x32 | 45,000 | 195,000 | 318,000 |
| Consolidat. | F1 | 2–8–0 | 1596 | 55 | 19x26 | 30,000 | 136,000 | 222,000 |
| 10-Wheel.. | E13 | 4–6–0 | 1713 | 55 | 19x24 | ...... | 110,000 | 192,000 |
| 10-Wheel.. | E6 | 4–6–0 | 2113 | 63 | 19x26 | 40,000 | 152,000 | 272,000 |
| Mogul..... | D5 | 2–6–0 | 1600 | 55 | 19x26 | 38,000 | 130,000 | 216,000 |
| 8-Wheel.. | B23 | 4–4–0 | 1600 | 63 | 18x24 | ...... | 94,000 | 168,000 |
| Switcher .. | A10 | 0–6–0 | 1846 | 49 | 19x28 | 45,600 | 137,000 | 212,000 |
| Switcher .. | A1 | 0–6–0 | 785 | 49 | 16x20 | 23,300 | 70,000 | 112,000 |

This is merely a good representative list of locomotives, for reference.

## PHYSICAL CHARACTERISTICS.

Modern steam locomotives in common railroad service have the following physical characteristics:

**A self-contained power unit** with water supply, coal supply, boiler, and two complete engines, is embodied. It is a power house on wheels, mounted on trucks and moving over track at speeds up to 60 m. p. h.

**The water supply** comes from many lakes, streams, and wells, and pumping stations are located 10 to 20 miles apart. Since alkali and mineralized waters must be used in many cases, they must be treated to prevent bad scaling, blistering of plates, foaming, and water in cylinder.

**The best coal,** bituminous screened lump, is used. Coal substations with handling machinery are located 20 to 50 miles apart. Energy is required to haul about 60 tons of water and coal supply with the train.

Coal for northern roads, those near Lake Superior and Lake Michigan, is purchased each year about April first. Youghiogheny run-of-pile is used, which has run over a 3/4 inch screen at the mine. The run-of-pile contains about 25 per cent. of good screenings, formed by the handling at the lake docks. The price paid by the railroads has increased from $2.30 to $3.00 per ton, or 30 per cent., within the

last seven years. The coal used by these northern railroads costs about $4.20 per ton delivered on the locomotive tender. (Youghiogheny screened lump costing, $3.50 at the dock, is sold by the coal companies to those manufacturing companies which are located at some distance from the railroad or which have poor facilities for burning coal. The screenings are burned by power plants which have stokers.)

Coal for railroads near and just west of Chicago is generally the best Illinois screened lump. The screenings and duff are burned on stokers in railway and manufacturing plants in the larger cities within 500 miles of the Illinois mines. Coal for eastern roads comes from Pennsylvania and Indiana. Fuel oil is commonly used on locomotives in the Southwest and on the Pacific coast. Anthracite coal is used by some roads with economy.

Statutes of states and municipal restrictions frequently compel the use by locomotives of an anthracite coal, coke, or fuel oil for switching and city service, and near flour mills, factories, forests, etc.

The cost of hauling an ordinary 60-ton coal and water tender as dead weight, in a freight train, at $0.005 per ton-mile, for an ordinary 133-mile trip is $4; and in a passenger train varies from $8 to $11 per trip.

The cost of locomotive fuel depends, therefore, upon the price, heat units, location of the road, cost of handling, etc., and on furnace economy.

**Compact boilers** of the fire-tube type, with fire-box furnaces for hand firing, have been universally adopted. A steam pressure of 200 pounds is used, not so much for economy as for capacity. Steam pressures of 150 pounds with superheat are now used to increase the economy, by reducing the radiation and condensation. The ratio of heating to grate surface depends on the grade of coal, and approximates 65 for ordinary bituminous coal. On a long run, the grates often burn several different kinds of coal, while the size of the grate, and the exhaust nozzle, are suited to but one grade of coal; and this is the cause of some complaints of firemen regarding poor steaming. The draft and the rate of combustion are proportional to the quantity and the pressure of the exhaust steam discharged thru the smoke stack. A draft at the smoke-box of about 3.7 inches by water gage is required to burn 100 pounds of bituminous coal per square foot of grate per hour.

**Center of gravity** is high, for the track gage. The center of gravity is in the boiler, which is above the top of the drivers. The diameter of the driving wheels of ordinary passenger locomotives is 60 to 84 inches; of freight locomotives is 51 to 63 inches; of switch locomotives is 48 to 51 inches, or less than one inch per mile per hour of maximum speed. The bearings on each axle of steam locomotives are *between* the wheels. The bearing spring centers are only 42 inches apart.

**Rigid driving-wheel bases** of passenger engines are from 10 to 13 feet long; of common freight engines, 10 to 17 feet. Longer rigid wheel bases for 4 and 5 sets of drivers are most destructive to curved track.

**Simple engines** and two cylinders are in general use. Only 5 per

cent. of all locomotives are compound, and these are used for special conditions. Two-cylinder compounds have increased the economy of fuel; but this type has its limitations in speed and power. In high-speed service, compounds are not economical, and are seldom used.

Cylinder diameters are so proportioned that, at 80 per cent. cut-off and with a 25 per cent. coefficient of adhesion between the rails and the weight on the drivers, the steam pressure will slip the drivers. The length of the stroke is 26 to 34 inches, the longer stroke for heavy freight service, the 26-inch for passenger service.

Cylinder diameters are designed for sufficient tractive power. Large cylinders, often compounded, are well separated, and there is a constant disturbance of the locomotive in a horizontal plane called "nosing" which is due to the alternate pressures and their lever arms.

**Designs** of the steam locomotive require that the materials and the power production be worked to the highest safe limits. The character of the labor must be considered. Complication is not tolerated. Mechanical stokers, coal crushers, feed-water heaters, superheaters, fire-brick arches, water-tube boilers, and economizers, which are desirable, are not used on ordinary locomotives, because economy of space and simplicity are essential. Quickness of repairs on the road is important. Expenses of maintenance and repairs at shop must be a minimum.

Steam locomotive service cannot be continuous. Its design requires time for blowing down, cooling off, and washing out the boilers, cleaning of tubes, adjusting gear of machinery, filling the boilers and the coal and water tender, and waiting for fresh fires.

Stationary engine practice cannot be used, as conditions of operation are essentially different. In the locomotive engine, steam passages cannot be short; piston and port clearance volumes cannot be small, and compression cannot be used to best advantage because, to a great extent, the exhaust nozzle and the draft required govern the back pressure.

Steam turbines, which are now the motive power used for electric railroads, have characteristics which are widely different from engines. The use of poppet valves avoids loss of pressure, superheat prevents condensation on the cylindrical walls, and a high vacuum is utilized to convert the maximum number of heat units into work.

**Weight** is prescribed, in the design, by the length of the connected wheel base allowed on curves; by a weight of 20 to 28 tons per axle to be borne by the rails; and by a weight of 3 tons per linear foot of track.

Weight efficiency, as shown by the table on "Proportions of Modern Steam Locomotives," is from 7 to 10 h. p. per ton. Weight efficiency is particularly low on large steam locomotives, because high speeds are not possible with complicated heavy reciprocating parts. Mallet designs with four cylinders and separated trucks distribute the weight.

**Capacity is limited by design,** as is outlined below:

Driving wheels are first loaded to the greatest allowable or safe weight the rails will bear—about 90 tons for 30-foot, 90-pound rails, or about 50,000 pounds per axle, when the track is reinforced. The number of drivers is generally limited to 4 pairs in freight and 3 pairs in passenger engines. Rigid driving-wheel bases must be limited to 13 feet in passenger engines, and 17 feet in freight engines to avoid destructive thrusts and mounting of curves. Driving wheel diameter is such that the reciprocating machinery will not work at a higher speed than 600 to 1300 feet per minute, depending upon the piston weight and diameter.

The boiler is placed above and clear of the drivers; yet it is dangerous to let the center of gravity exceed a height of 8.0 feet, for the 4.71-foot wheel gage. The boiler is provided with enough heating surface, in its diameter and length, to supply the steam. The boiler must be planned without lengthening the wheel base beyond the permissible limits noted. About 150 Santa Fe special freight locomotives use 19.5-foot rigid wheel bases, with close-coupled drivers, but that limit exceeds good practice. Mallets are more flexible, and use 10- to 16-foot rigid wheel bases.

Grates must have ample size to burn the coal. Fire-boxes must have ample length and depth, so that the flames will be kept from contact with the plates until some part of the combustion is completed. Good design of fire-boxes is exceedingly difficult on account of the required support and shape, and the expansion and warping. The track gage is not wide enough for good proportions, especially where large boiler capacity is needed.

Large steam locomotives are thus hard to design, and are often unsatisfactory. The failures in such locomotives multiply as the size increases. The men operating the complicated moving boiler and engine plant are not sufficiently skilled, nor can they give the machinery sufficient attention. Repairs and renewals cannot be made in the usual way, with jacks, wedges, and chain blocks.

"The time out of service and the repairs per 1000 ton-miles hauled are out of direct proportion to increased weight. Large broken castings become common. Leaky flues are troublesome. Its own extra dead weight, with coal and water tender, must be propelled. Two firemen become necessary. Condensed steam in the large cylinders of compounds decreases the efficiency. Compression troubles and condensation demand numerous relief valves. Leaks surround the engine with clouds, which are annoying and dangerous. The large locomotive boiler is wrong in principle." Railway Age, April 3, 1903.

"The men in charge of the railways in this country have struggled for nearly 15 years with the greatest problem of our times, how to move a load whose weight increases from 10 to 15 per cent. a year with a locomotive whose power increases at about 2 1/2 per cent. a year. The limit of safe, speedy, and reasonable service with existing facilities has been reached." J. J. Hill to Kansas City Commercial Club, Nov., 1907.

**Heating surface** of locomotives for switching and local passenger service ordinarily varies from 1200 to 1500 square feet; for ordinary passenger and express service from 1500 to 2500; for heavy passenger and way-freight, from 2200 to 2500; for heaviest passenger and heavy freight, from 2500 to 3200; for steep grades, from 3200 to 3500; for mountain grade service, and as pushers, from 3500 to 8000 square feet.

Total equivalent heating surface is based on the tube and plate heating surface, plus 1 1/2 times the superheating surface.

The horse power of a steam locomotive, the grade of coal and the design being fixed, depends upon the boiler heating surface.

**The torque,** or the **tractive force** at the rim of the drivers, or the **drawbar pull** plus the pull for the engine friction, expressed in pounds, is proportional to the product of the steam pressure of the boiler, in pounds per square inch, $P$; the ratio of mean-effective pressure to boiler pressure, $Y$; the cross-sectional area of one cylinder, in square inches, $0.7854 \times D^2$; and the length of piston stroke, in inches, $L$; divided by the diameter of the drivers, in inches, $W$.

The running drawbar pull, or torque, for the locomotive and train is

$$\frac{Y \times P \times D^2 \times .7854 \times L \times 4}{3.14 \times W} = \frac{Y \times P \times D^2 \times L}{W}, \text{ in pounds.}$$

The maximum drawbar pull, or tractive force, or torque, is $Y \times P \times D^2 \times L/W$, in pounds. The variable Y, at slowest speeds, is about .80 of the boiler pressure, and at highest speeds, is from .30 to .20 of the boiler pressure. The reciprocating pressure from the several pistons furnishes a variable tractive effort.

**Reference:** Carpenter: Railway Age Gazette, Jan. 28, 1910.

The maximum drawbar pull, by design, is made equal to about 25 per cent. of the weight on drivers, assuming good conditions, and sand. The draft gear of the cars in a train, in common practice, is limited in strength to about 45,000 pounds. Articulated Mallet compounds, which may exert 70,000 pounds drawbar pull as a maximum and 50,000 pounds at very slow speed, are generally used as pushers.

**The piston speed,** in feet per minute, is simply

$$\frac{M.P.H. \times 5280 \times 2}{3.14 \times 60} \times \frac{L}{W} = M.P.H. \times 56 \times \frac{L}{W}.$$

**Horse power,** or rate of work, of steam locomotives is generally computed on the basis of 12 pounds of steam per hour per square foot of boiler heating surface, and 28 pounds of steam per indicated h. p. hr. Horse power $= 0.43 \times$ square feet of heating surface. Goss.

Horse power is always the product of the pull or push, in pounds, times the speed, in feet per minute, divided by 33,000.

$$H.P. = \frac{\text{Pull} \times F.P.M.}{33{,}000} = \frac{\text{Pull} \times 5280}{33{,}000 \times 60} = \frac{\text{Pull} \times M.P.H.}{375}.$$

**Indicated horse power** of two simple cylinders is the product of the mean effective steam pressure, $Y$ times $P$, in pounds; area of one piston face, in square inches, $D^2 \times 0.785$; length of the stroke, in inches, $L$; strokes per revolution, 4; number of revolutions of the drivers per minute, divided by 33,000.

$$H.P. = Y \times P \times D^2 \times 0.785 \times \frac{L}{12} \times 4 \times \frac{R.P.M.}{33{,}000} \text{ (Do not reduce.)}$$

## OPERATING CHARACTERISTICS OF STEAM LOCOMOTIVES.

**Furnace conditions** in locomotive boilers are such that combustion is not perfect. Hydrocarbons which are distilled from the coal by the furnace heat ignite, and the carbon in the flame combines with the oxygen and becomes an invisible gas, *provided* there is a fraction of a second in which combustion may be completed; but in a locomotive furnace the time is short, and the distance from the coal to the steel is short, and these carbon particles in the flame, with a temperature of about 2000° F., come in contact with the relatively cold fire-box plates and the tubes; and cooled carbon cannot unite with oxygen, but passes out of the stack as black smoke.

Fire-brick arches over the furnace steady the furnace temperature, prevent flame contact with the steel, and improve the combustion of the gases; but they are seldom used, because they require water tubes which fill with mud, burst, and kill firemen; and the arches are in the way, interfering with flue repairs. Fire-brick arches are smoke preventers; they decrease the warping in the furnace, and reduce the tube failures.

Lake Shore Railroad is almost alone among the railroads in having nearly all of its locomotives, including switch engines, fitted with fire-brick arches. Its success is largely due to the use of brick in small units, supported on arch tubes, these tubes being kept clean by a hydraulic tube cleaner. The Lake Shore Railroad has demonstrated beyond a doubt the advantages of these arches. The estimated saving in fuel per annum amounts to a half-million dollars, in addition to a large saving which is due to reduction in tube repairs. The life of the arch, in passenger engines, averages one month, in freight engines 1 1/2 months, and in switching engines 4 to 5 months. Consult: Ry. Age, March 4, 1910, p. 504; June 2, 1911, p. 1264; Sci. Ame., April 24, 1909.

Smokeless operation of furnaces, by stokers or by hand firing, requires a somewhat *uniform* load; yet on a locomotive the load is most variable. Mechanical stokers feed coal with regularity, but require much space and for ordinary locomotives are complicated. With hand firing, the coal is carried and is thrown too far for efficient distribution; and air holes and chilled furnace gases are common. The smoke nuisance, caused by these furnace conditions in modern heavy service, is an uneconomical feature.

**High rates of evaporation** are required. The coal consumption with the maximum continued rate of serving runs up to 200 pounds of bituminous coal per square foot of grate per hour; and the actual water then evaporated is about 4.5 pounds per pound of coal, while with economical rates of firing, the ratio is increased to 6.4 pounds, or 42 per cent. The economy decreases as the rate of work increases.

The water evaporated per pound of best Illinois coal, with 12,000 B. t. u., per square foot of grate surface per hour in modern steam locomotives, is given below, in a table based on average results with feed water at about 60° F., evaporated into steam at 200 pounds pressure.

COAL CONSUMPTION AND EVAPORATION RATIO.

| Rate of consumption. | Coal per square ft. of grate per hour. | Ratio of evaporation. | |
|---|---|---|---|
| | | Actual. | From and at. |
| Maximum rate | 200 lbs. | 4.50 | 5.46 |
| High rate | 160 | 4.85 | 5.90 |
| Ordinary rate | 100 | 5.33 | 6.47 |
| Average rate | 80 | 6.00 | 7.28 |
| Economical rate | 65 | 6.40 | 7.77 |
| Central power-plants rate | 60 | 7.00 to 8.00 | 8.50 to 10.00 |

With high rates of evaporation, particularly with foaming waters, low water is carried in the boiler to prevent an excess of water and spray from reaching the cylinders.

**Heat radiation** from about 500 square feet of the external boiler surface of a moving boiler, about one-third of which can be lagged with mineral wool, requires 60 pounds of coal per hour in the mildest weather. Much fuel is consumed while coasting and stopping, but particularly while waiting. Freight locomotive records, which have been averaged for several divisions, show that 30 per cent. of the time is spent in waiting. Cold weather increases the pounds of coal used per ton-mile, a large part of which may be accounted for by radiation. Condensation on the cylinder walls and piston rods also increases rapidly in winter.

**Stand-by losses** require that each boiler, nearly full of hot water, be blown off daily, and heat is wasted. The tubes are then washed out and cleaned. Firing-up requires 500 pounds of coal in small locomotives, 800 in medium, and from 1,200 to 1,600 in the largest locomotives. An engine does not go into service when the boiler is up to full pressure, for the train dispatcher prefers to have many locomotives ready for service. While waiting, the coal burned may equal the coal utilized for the run.

**Weather ratings,** or relative tonnage hauled by locomotives, vary. The table used by the Great Northern Railway follows:

| | |
|---|---|
| Temperature between 25° and 0° | 100 per cent. |
| Very frosty or wet; 25° to 5° above zero | 90 per cent. |
| 5° above to 10° below zero | 80 per cent. |
| 10° below and colder, and not windy | 75 per cent. |

Capacity is decreased by the chilled furnace, radiation of heat, condensation of steam, increased friction, etc. See data by Henderson, page 82, on "Pounds of Coal per 1000 Ton-miles."

**Operation of locomotive boilers and engines** depends primarily upon the attendants. The complicated machinery may not get proper attention from the engineman and fireman. They are occupied with the combustion of fuel, the production of mechanical power, the care of the reciprocating mechanism, and the heed which must, as a matter of safety, be given to the track and signals. Reliability of service takes precedence over both economy of operation and careful attention to machinery. A locomotive that cannot be operated successfully by an ordinary engineman, is not adapted to common train service.

**Unbalanced forces** from common drivers are large. The horizontal reciprocating forces, which vary from 6 to 10 tons per piston, and the weight of the rods, cross head, and wrist pin may be neutralized by a counterbalance. The centrifugal force, however, acting on the counterweight, varies as the square of the speed, and produces a violent unbalanced vertical force, which, when the speed is high, may cause the wheels to first deliver a terrific blow on the rails, followed by a tendency to lift from the rails at every revolution. The centrifugal forces at maximum speed must not exceed 80 per cent. of the weight on the rail, or the wheels will not be maintained solidly on the rail. The counter-balance in the drivers can be suited to but one speed. Track pounding necessarily results.

Balanced locomotives are worthy of much consideration because of the decreased track maintenance, increased safety, and greater allowable rail pressure per wheel. Cranks in the middle of the driving axle are objectionable. Few balanced locomotives are used, because, with the limited space for the crank axle the design is difficult. See Walker, on Compensated Locomotives, Ry. Age, Aug. 14, 1908.

American Locomotive Company has recently built many 100-ton Atlantic engines with four simple, or four compound cylinders, arranged on the balanced principle. The crank axle is the front driver axle. This type of engine has been selected by the Chicago, Rock Island & Pacific Railroad for high-speed passenger work, because it is easier on track and bridges. Atkinson, Topeka & Santa Fe uses 171 balanced 4-cylinder compounds. See Ry. Age, Dec. 23, 1910; Jan. 7, 1911.

**Track destruction** of roadbed and bridges is not caused by the loads from the many heavy steel cars. It is caused largely by unbalanced forces of locomotives, combined with excessive weight, concentration of weight, rigid wheel bases, and nosing. Track pounding wastes power; it destroys special work; it produces broken rails. The terrific reaction and the vibration rack the engine frame as well as the roadbed. Broken driver axles and crank shafts frequently cause wrecks. Locomotive weight per horse power is excessive, and it is generally concentrated. Engines with a long, rigid wheel base are hardest on curves; the oiled flanges of drivers wear rapidly, while flanges of car wheels wear slowly. Nosing of engines, caused by an alternating force of many tons from steam pressure on the piston, and the leverage from the widely spread cylinders, on each side of the locomotive, is also destructive, for it loosens the spikes, spreads the rails, and is a source of danger in transportation.

**Friction losses** of steam locomotives are caused by the wear of heavy reciprocating pistons, rings, rods, cross heads, valve gear, and connecting links. The wear of valves and cylinders is excessive, both because of lack of lubrication and because of scaly and foaming water.

"Even with a good means of supplying lubricant, there appears to be a high percentage of the power of a locomotive engine using high-pressure steam absorbed in overcoming internal resistance." Sinclair.

"The internal friction of the simple locomotive cylinders is equivalent to 3.8 pounds mean-effective pressure." Goss. This is a large part of the total mean-effective steam pressure. Seven per cent. is allowed for the internal friction of compound locomotives, and more, when superheat is attempted. Friction in Mallet compounds, in practice, is such that a Mallet without steam will not drift in going down a 1.2 per cent. grade, or the friction exceeds 24 pounds per ton. Great Northern Railway 252-ton Mallets, used in pushing service on the Cascade Division, will not drift down a steeper grade.

The power required to propel the simple steam locomotive is large, because the weight, internal friction, and head-end resistance are excessive. Note the following:

"Aspinwall found that the 10-wheeled locomotive with tender absorbed 32 per cent. of the total power of the train. Mr. W. M. Smith has given the result of his experiments as about 36 per cent. of the total power; and Mr. Druit Halpin has found that the engine and tender on the Eastern Railway of France absorbed 57 per cent. of the total power developed; Dr. P. H. Dudley gave it as 55 per cent.; Mr. Barbier as 48 per cent. These figures appear much too high. Probably 35 per cent. is a proper allowance for ordinary trains, the actual figures depending upon the speed, the wheel base, the unbalanced effort, the service, and the load behind the engine and its coal and water tender." Inst. of C. E., 1901, p. 197.

LABORATORY TEST ON FRICTION OF ATLANTIC TYPE LOCOMOTIVE

Cylinders, 20½x26; drivers 80-inch; weight on drivers 55 tons; heating surface 2320 sq. ft. Test by Pennsylvania Railroad, 1910.

| Rev. per min. | Piston speed f.p.m. | Miles per hour. | Drawbar pull pounds. | Cylinder h.p. | Drawbar h.p. | Loss in friction h.p. | Steam per i.h.p.h. |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 22,000 | 0 | 0 | 0 | .......... |
| 80 | 346 | 19.0 | 16,768 | 940 | 850 | 90 | 32.3 |
| 120 | 520 | 28.5 | 12,384 | 1075 | 940 | 135 | 28.0 |
| 160 | 694 | 38.0 | 9,602 | 1150 | 975 | 175 | 26.3 |
| 200 | 866 | 47.6 | 7,894 | 1220 | 1000 | 220 | 24.9 |
| 240 | 1040 | 57.0 | 6,428 | 1240 | 975 | 265 | 24.4 |
| 280 | 1213 | 66.5 | 5,325 | 1250 | 945 | 305 | 24.0 |

Machine friction, with oil lubrication of driver axle bearings, was fairly uniform, and was equal to about 1687 pounds drawbar pull.

ROAD TEST ON FRICTION OF PACIFIC TYPE LOCOMOTIVE.

Cylinders, 22x28; drivers, 79-inch; weight on drivers, 80 tons; rigid driver-wheel base, 17 feet. Test by New York Central Railroad, 1909.

Friction of mechanism and head air resistance of a Pacific type locomotive on the "Twentieth Century Limited" was tested with the following results:

A 5-car, 315-ton train, at 70 m. p. h. required 3617 pounds tractive effort or 11.5 pounds per ton for the cars, and 4551 pounds or 22.7 pounds per ton for the 200-ton, 22x28 locomotive.

An 8-car, 505-ton train at 62 m. p. h. required 4950 pounds or 9.8 pounds per ton for the cars, and 4055 pounds or 20.3 pounds per ton for the locomotive.

A 9-car, 564-ton train at 60 m. p. h. required 5335 pounds or 9.5 pounds per ton for the cars and 3959 pounds or 19.8 pounds per ton for the locomotive; in other words, about twice as much per ton for the locomotive as for the cars.

Pacific type locomotives on New York Central "Twentieth Century Limited" trains in 1911 show the following:

Boiler combustion chamber 4 feet long; heating surface, tubes and fire-box, 2915 square feet, superheating tubes 493 square feet, total equivalent heating surface 3655 square feet. Center of boiler above the rails, 9 feet, 9 inches. Driving-wheel base, 14 feet. Cylinders, simple, 22x28. Drivers, 79 inches.

Boiler pressure 205 pounds, dry pipe pressure 185 pounds, steam chest pressure 170 pounds, drop in pressure thru superheater 15 pounds, superheat 185° F.

Weight of locomotive 212 tons, of engine 131 tons, on drivers 85 tons. Trailing load 7 steel Pullman cars, 443 tons; weight of locomotive, 32 per cent. of total weight; speed on level, 60 miles per hour. Ry. Age, March 31, 1911, pp. 785 to 795.

**Speed of trains is limited** by the heating surface of the boiler. The power developed by the cylinders is restricted, because the rate of steam

generation is fixed. The tractive effort cannot be maintained as the speed increases. The mechanical power developed is a minimum on the heavy grades, because of the low cylinder efficiency with half cut-offs; while it is at a maximum on the level, or for light loads, and at high speed, as is explained later. A constant rate of steam being available, speed is to be increased only when the drawbar pull is decreased.

About 60 m. p. h. is the limit with a Pacific type locomotive, with tender, weighing 200 tons, and a train of 6 modern 55-ton steel coaches.

American Railway Engineering Association constants for resistance of a steam locomotive with 125 square feet of cross-section, at 60 m. p. h., show:

Head end or air resistance $R = .002V^2A$, or 900 pounds.

Internal friction between cylinder and drivers, $R = 18.7\ T + 80X$ or 1830 pounds.

Engine and tender truck resistance is $R = 2.6\ TT + 20\ XX$, or 720 pounds.

Total resistance of locomotive at 60 m. p. h. is 3450 pounds; or 550 h. p. is required for the minimum friction of the locomotive. It increases greatly in winter.

The tractive resistance of six 55-ton coaches at 10 pounds per ton is 3300 pounds; and the total resistance of the train is 6750 pounds. At 60 miles per hour, the train then requires 1080 h. p. On a very light gradient, 10.5 feet per mile, or 0.2 per cent., the resistance due to the grade is 2120 pounds. The total h. p. is then 1420. This requires at least 1420/0.43 or 3300 square feet of heating surface.

A locomotive with greater heating surface increases rapidly in weight of engine and of coal and water tender, and cannot propel a train at a higher speed.

Limitations are also imposed at high speed by the valve and the valve gear which allow only a small volume of steam to get *into* the cylinder and cause a high back pressure in getting the steam *out* thru the exhaust nozzle.

**Reference:** Ry. Age Gazette, Editorial and data, Dec. 24, 1909; Nov. 11, 1910.

**Mechanical strains** in the boilers are interesting. Frames can hardly be made strong enough. The boiler, with all its bracing and binding, is not self-sustaining. With varying track alignment, it yields from its own weight and from the cylinder strains. Where the belly braces are riveted to the barrel of the boiler, the sheets around the edge of the rivets become grooved, because of continual motion. This chafing at the braces of boilers indicates the resistance offered to mechanical strains. Braces must be more or less yielding. Shocks, collisions, and ordinary bumps are harder on the boiler than on the engine and frames.

Temperature strains in the furnace and boiler cause unequal expansion and contraction, which are of a serious nature. The steam pressure in the boiler varies daily from zero to a maximum.

**Locomotive repairs** are of a particular nature. Mechanical vibration at high speeds destroys the metal by fatigue and crystallization. Temperature strains are destructive. Fire-box repairs, caused by excessive temperature strains, always increase radically in winter. Stay bolts are broken by the constant bending backward and forward, from the differ-

ence in expansion between the shell sheets and the fire-box. They are the most expensive and troublesome things about the boiler. Broken stay bolts, combined with low water and hot crowns, are the most prolific cause of explosions.

Tube troubles are caused by temperature strains and by incrustation and corrosion from bad and varying waters. The scale formed is frequently of a hard, strong, porcelain nature, and lowers the boiler efficiency and capacity. The scale must be washed out after each 500-mile run. The use of soft water, during rainy seasons, or at other times, and the use of compounds loosen the scale, which may lodge and fill the space between the tubes, or on the lower tubes, to their disadvantage. Corrosion from compounds and acidulated water reduce the strength of materials and cause leaky tubes. Bad water west of the Mississippi River appreciably increases the cost of maintenance.

General overhauling in the back shop is required of modern freight locomotives about every 60,000 miles, and of passenger locomotives about every 80,000 miles, during which 200 to 300 flues, about 0.12 inch thick, are removed, cleaned, and renewed, and the stay bolts renewed.

The nature of these operating facts is of importance.

"Repairs of large engines are usually very expensive. Their fire-box plates are so severely tried by the fierce combustion, and by expansion and contraction, as to require frequent renewal. Strenuous endeavors are made to secure the best material for this purpose, yet a sheet has been known to show more than 150 cracks after a short service. Also, the great weight of the reciprocating parts aggravates the destructive effect of a lack of balance in those parts, and consequently these monsters soon pound flat places in the tires of drivers, and must be sent to the shop to have those defects turned off." E. E. Woodman.

"Running repairs of compound locomotives have cost nearly double as much as the simple engines per mile; also by spending so much time in the shop their annual mileage is very much less. This must not be thought to apply to all compounds, but as a general proposition it indicates the value of simplicity in minimizing the cost of repairs." Henderson.

"Few master mechanics are satisfied with the performance of large cylinder locomotives, the complaint being heard on all sides that they are not nearly so good for their inches as smaller engines." "The steam ports are seldom proportionately as large. A serious proportion of the added power is lost by friction. A great portion of the steam is condensed by the increase of cylinder area. Rubbing surface in a cylinder induces a greater friction and causes much greater internal resistance than any other part of the engine, except the slide valve, consequently every effort should be made to reduce this surface." Sinclair.

Opinions of many operators affirm these facts.

The writer advocates large locomotives with compounding and superheat. It is true that the large locomotives are unsatisfactory, that the large compounds, of some types, are hard to keep out of the shop, that superheat increases the valve and engine friction, and that the main-

tenance expense per mile is greater in proportion to the weight and hauling capacity than with smaller locomotives; but the transportation department is getting the freight hauled at a lower cost *per ton-mile.*

**Condensation** in the cylinders is evident because the hyperbolic curve of expansion is not followed. The refrigerating influence of the cylinder walls and of the exposed piston rod is large. Steam jacketing is impracticable, and good lagging is only a partial preventive. The cylinder acts first as a condenser and then as a re-vaporizer of steam.

The discovery that the great difference between the weight of water fed into the boiler and the weight of the steam accounted for by the indicator card, a difference which is due to the weight of the steam condensed, is accredited to Isherwood.

"Leading engineers, who have devoted much attention to investigating the extent of cylinder condensation, have shown that, in engines cutting off steam earlier than half-stroke, the loss from cylinder condensation is seldom less than 20 per cent. of all the steam entering the cylinders, and that it often rises to 50 per cent. and upward." Sinclair.

**Superheat** reduces the cylinder condensation, and, while it requires additional coal, ultimately increases the economy of fuel. Superheat is advantageous on long, steady runs and on long, steep up-grades. The advantage is small for runs composed of up- and down-gradients, or on runs with frequent stops. Capacity may be gained to haul heavier loads on mountain grades.

Superheat requires piston valves, to prevent excessive warping, friction, and cutting, which, in simple engines, rapidly increase the leakage thru the valves and past the main pistons, and therefore increases the coal consumption.

**Reference:** Ry. Age Gazette, Jan. 20, 1911, p. 110.

Superheat on compound locomotives is advantageous; but it causes greater friction in the larger cylinders, and, in common operation, radically increases delays and maintenance expense. A gain is made with superheat by lowering the steam pressure to decrease the radiation, but the weight and friction of heavy reciprocating pistons are thereby increased. Superheating is desirable, and with temperatures of 560 to 660° F., gains are being made in economy.

**Steam consumption** per indicated h.p. hour for simple engines which are new or in good condition averages about 30 pounds; for simple engines in ordinary conditions it is about 36 pounds. When the locomotive furnace, boiler, and cylinder are chilled in cold weather and on overloads or underloads, the steam consumption increases rapidly. In a pamphlet recently issued by the Baldwin Locomotive Works, Mr. W. P. Evans gives some figures relating to actual efficiency of modern locomo-

tives, and calls attention to the improved economy of 4-cylinder compound locomotives.

"The weight of steam per h.p. hour, for the single-expansion engine, is 34.12 pounds, and for the balanced compound, 29.2 pounds, representing a saving of 17 per cent. The other important improvement in locomotives is superheating, which is claimed to have saved, in freight service, 26.7 per cent., and in passenger service, 22.8 per cent., according to a Canadian Pacific Railway test."

St. Louis Exposition tests of 1906, in a building, showed better results; and, for slow-speed service, a gain was shown by compounding.

An average consumption of about 10 pounds of steam per h.p. hour is obtained with steam turbines.

**Economy of coal** cannot be attained in locomotive practice. The ordinary use of coal shows an enormous waste. The U. S. Geological Survey, thru its technologic branch, has conducted many tests on locomotives to determine how the waste in operation could be avoided. Prof. W. F. M. Goss reported, November, 1909, in Bulletin 402, that 20 per cent. of the total coal production of the country, costing the railroads $170,500,000 per year, was used by 51,000 steam locomotives. The following statistics are taken from the government report:

COAL WASTE BY LOCOMOTIVES.

| Coal. | Tons. | P.C. |
|---|---|---|
| The locomotive coal used in 1906 was | 90,000,000 | 100.0 |
| Lost through heat in gases from the stacks | 10,080,000 | 11.2 |
| Lost through cinders and sparks | 8,640,000 | 9.6 |
| Lost through radiation and leakage | 5,040,000 | 5.6 |
| Lost through unconsumed coal in ashes | 2,880,000 | 3.2 |
| Lost through incomplete combustion of gases | 720,000 | .8 |
| Used in starting fires, keeping hot, standing at sidings | 18,000,000 | 20.0 |
| Total losses and waste | 45,360,000 | 50.4 |
| Used for hauling trains | 44,640,000 | 49.6 |

Professor Goss thus shows that one-half of the coal is wasted. He suggests small improvements, such as increased grate area, brick arches, greater care in selecting fuel, less loss of fuel by dropping thru grates, and more skilled firing.

"Locomotive boilers are handicapped by the requirements that the boiler and all its appurtenances must come within rigidly defined limits of space, and by the fact that they are forced to work at very high rates of power."

"Future progress cannot be rapid or easy, and must be from a series

of relatively small savings, which, if made by a large proportion of the locomotives of the country, would constitute an important factor in the conservatism of the nation's fuel supply."

Load factor of steam locomotives is low, and as a direct result economy of coal is low. Boilers have fairly good efficiency; but the engines have that economy which is usual with prime movers having small limits of expansion, large clearance and condensation, and an efficient load for 25 to 30 per cent. of the total hours in service.

## SPEED-TORQUE CHARACTERISTICS OF STEAM LOCOMOTIVES.

The speed-torque characteristics of steam locomotives are seldom referred to in text-books on steam locomotives. The information herein presented was obtained at first hand from indicator diagrams, operating data, dynamometer records, reports on locomotive tests, and from master mechanics and superintendents of motive power of steam roads. The data represent averages, yet may be readily modified for local conditions.

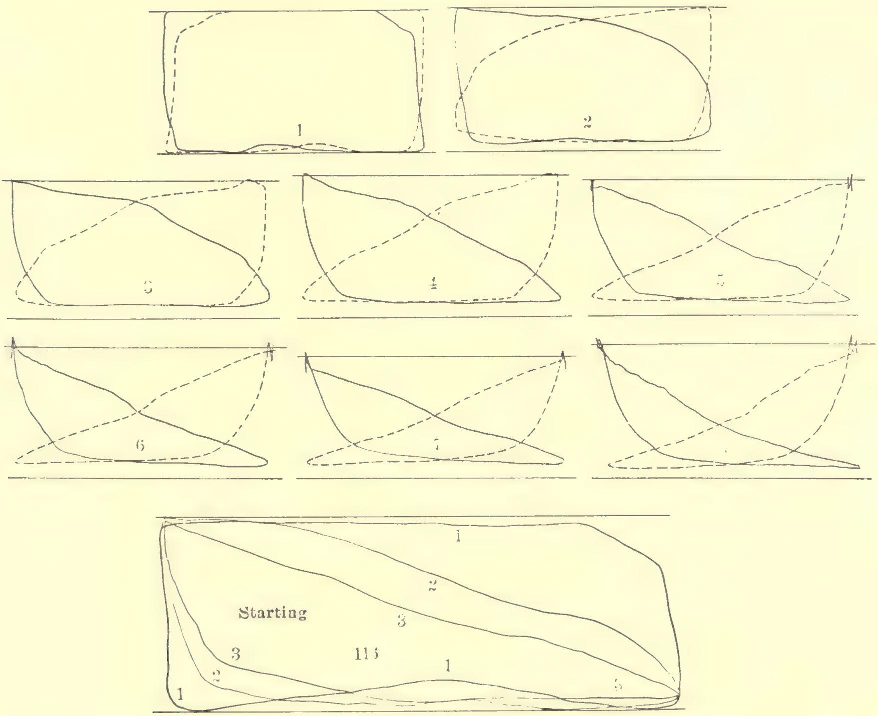


FIG. 22.—STUDY OF INDICATOR CARDS OF SIMPLE STEAM LOCOMOTIVES.
Cards 1-8 were taken during the passenger locomotive test, noted below. The lower card, 116, is from an indicator card taken at one end of the cylinder during the first three revolutions while a 20x32 freight locomotive was starting.

Characteristics are studied and compared by means of curves which show how speed, torque, and power vary with respect to each other. (The relation of time to speed, known as acceleration curves, are important in a study of suburban service, but relatively unimportant in main-line railroad work.)

Speed-torque curves show the results obtained from the steam after it leaves the boiler, and they are of fundamental importance.

**Indicator diagrams** furnish a record of the action of steam in the locomotive cylinder. Many of the features of the indicator diagram of the steam locomotive are due to the variable speed requirements, and the limitations of space between the rail gage lines and within the rigid wheel base. Economy of material, and maximum capacity within a given space, are essential. A complete and simple power equipment, suitable for hard and reliable service, is the first necessity.

TEST OF A SIMPLE ENGINE.

Locomotive weight, including a 50-ton tender, 130 tons. Cylinders, 20x26 inches. Drivers, 80 inches. Heating surface, 3016 square feet. Load, a 450-ton all-coach passenger train.

| Card No. | Boiler press. | Cylinder pressure. | | Cut-off inches. | Train speed. | Piston speed. | Horse power. |
|---|---|---|---|---|---|---|---|
| | | mean. | per cent. | | | | |
| 1 | 195 | 182.3 | 93.5 | 21.00 | ......... | ......... | ......... |
| 2 | 190 | 120.0 | 63.1 | 10.75 | 30 | 546 | 1256 |
| 3 | 195 | 99.1 | 50.8 | 12.00 | 40 | 728 | 1383 |
| 4 | 185 | 76.3 | 41.2 | 11.25 | 50 | 910 | 1331 |
| 5 | 185 | 63.3 | 34.3 | 10.75 | 60 | 1092 | 1325 |
| 6 | 170 | 52.7 | 31.0 | 10.75 | 65 | 1183 | 1195 |
| 7 | 180 | 47.7 | 26.5 | 8.50 | 70 | 1274 | 1165 |
| 8 | 175 | 55.2 | 31.2 | 10.75 | 70 | 1274 | 1338 |

Ordinary indicator cards, as in the accompanying figures, show:

**Strokes** are short, 24 to 32 inches, commonly 26 or 30.

**Piston speeds** are high, 1000 to 1400 feet per minute. Large compounds do not exceed 600, because the friction of heavy pistons at higher piston speed is excessive. The revolutions per minute depend upon the diameter of the drivers.

**Initial steam pressure** is 200 pounds per square inch, to obtain capacity. With superheat, a lower pressure is used.

**Loss of pressure** occurs between the boiler and the steam chest, varying from 1 per cent. in starting to 7 per cent. at a piston speed of 700 feet, and to 13 per cent. at 1400 feet per minute. The abnormal loss in pressure is caused by wire-drawing, thru the ports and passages.

**Indefinite points of cut-off,** of release, and of compression are noted. These are due to inertia of the steam, loss of pressure between the steam chest and the cylinder, and friction thru the valves.

**Clearance** between the piston and the valve seat is from 8 to 10 per cent. of the volume of the stroke. Large clearance is necessary in design to prevent damage by water; but is accompanied by a material reduction in efficiency.

**Back pressure** is high, because of the restricted exhaust and the necessity of producing a draft for the fire; and it requires 10 to 15 per cent. of the initial pressure. Back pressure limits the mean effective steam pressure and the speed of the locomotive.

**Expansion of steam** indicates an uneconomical utilization of steam by the engines. The number of expansions is seldom over four.

Walschaert, Allen, Wilson, and other valves and gearing show that designers recognize the importance of giving the steam ample opportunity for rapidly entering and leaving the cylinders, the object in view being to raise the steam line and lower the exhaust or back pressure line. The valve openings produced by the best mechanism are unsatisfactory. The small port openings limit the steam at high speed and early cut-offs. Compression begins near the middle of the return stroke, not as in Corliss engines.

"Some good, practical valve motions have been produced embodying the idea of giving a prompt opening and closure of the steam ports, and permitting steam to be put in the cylinders of locomotives more quickly; but there is no evidence that they effect any economy in the use of steam." Sinclair.

**References:** Report of American Railway Master Mechanics' Association, June, 1907; Walschaert Valve Gear, Railway Age Gazette, Sept. 2, 1910.

**Mean effective pressure decreases as the speed increases.**—Note that:

At low speed there is the largest card, the greatest mean-effective pressure, and a high back pressure.

Increased speed, with 3/4 to 1/2 cut-off, is accompanied by a decrease in the initial pressure received at the cylinder, an increase in back pressure, and a reduction in the mean effective pressure as the steam expands. The reduced mean effective pressure limits the capacity of the locomotive for high-speed passenger service.

High-speed cards show a comparatively small area, and a further reduction in mean effective pressure.

When the piston speed exceeds 1000 feet per minute, the valve gear will not admit steam fast enough. The loss in pressure because of wire-drawing and condensation decreases the mean effective pressure faster than the mechanical gain due to the increase in piston speed.

**A definite relation exists between the mean effective steam pressure and the piston speed,** as a collection and tabulation of results from a great number of indicator cards show. The general relation is exhibited in the accompanying curve. The data for the curve were first obtained from F. J. Cole, Mechanical Engineer of the American Locomotive Company's Engineering Dept., Schenectady, N. Y. Mr. Cole states: "This curve, showing the relation between the mean effective pressure and the piston speed, was plotted on a large scale, from many hundred indicator diagrams, and represents an average result, taken from different types of locomotives under various conditions of service. The data are for a wide-open throttle, when presumably the cut-off was adjusted so that the locomotive

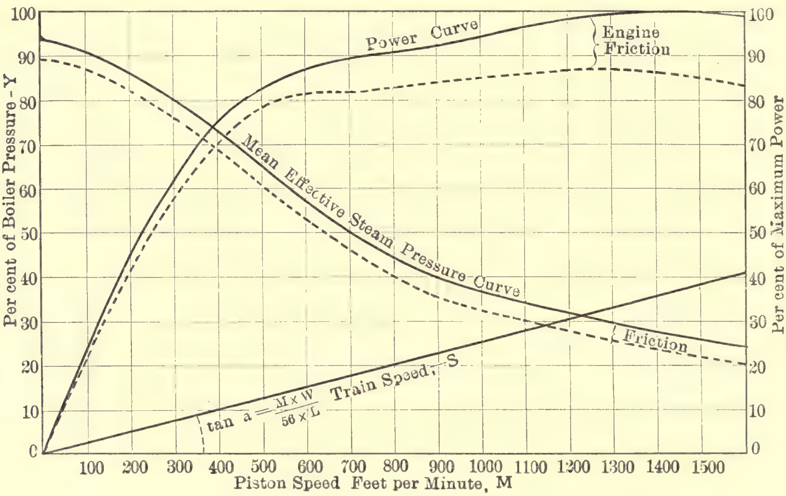


FIG. 23.—CHARACTERISTIC CURVES OF A SIMPLE STEAM LOCOMOTIVE.

was doing the best work at that speed. The curve represents the average best maximum mean effective pressure for different piston speeds under ordinary conditions, with simple locomotives. There are, of course, limitations due to the capacity of the boiler, size of pipes, kind of valve gear, and the builds of different locomotive companies."

The curve has been carefully checked by data from indicator cards taken from Baldwin and Schenectady locomotives with 26-inch strokes for passenger, and 28-, 30-, and 32-inch strokes, for freight locomotives.

The relation exists between the mean effective pressure and the *piston speed*, and there is no general relation between mean effective steam pressure and revolutions per minute, independent of the piston stroke, as some early writers have thought.

The locomotive has one point of cut-off for a given speed, at which point the engine will develop its greatest power. As the piston speed increases, the length of

the cut-off is decreased, and the expansion curve prolonged, so that, at the time of release, the pressure will be sufficiently reduced to allow the exhaust to take place without undue back pressure. If the cut-off is too great for the piston speed, the mean effective pressure will be decreased by port friction and back pressure.

**Work done in the cylinders,** expressed in h. p., is the product of the mean effective pressure, times the area of one cylinder, times the length of the stroke in feet, times the number of strokes of both cylinders per minute, divided by 33,000 foot-pounds per minute.

The product of the ordinates of the mean effective steam pressure curve, times those of the train speed curve, gives the power curve, shown in the accompanying curve. All data are in per cent., at the varying piston speeds. Only a small increase in power is obtainable after the piston speed exceeds 600 feet per minute.

The work done, or the h. p., is quite constant for all normal running speeds. The load diagram of steam locomotives, when plotted on a time base, is therefore nearly a horizontal line.

## COMPOUND LOCOMOTIVES.

Compound locomotives must be noted briefly. Only 5 per cent. of all locomotives are compounds, and these are generally used on heavy grades. Four-cylinder Baldwin compounds, and two-cylinder American cross-compounds are in use. They are started as simple engines.

The general relation of mean effective pressure to piston speed, which was explained, holds also for compounds.

The compound engine results from a desire to economize in fuel, by reducing the condensation and by decreasing the extremes of temperature in each of the two cylinders used in a combination.

D. K. Clark, the eminent engineer, showed 60 years ago, regarding operation of simple engines, that "expansive working was expensive working," because the cylinder acted alternately as a condenser and a revaporizer. It is also evident that, when live steam is condensed into spray by the refrigerating influence of relatively cold cylinders and rods, the steam loses its power to do mechanical work.

Compound locomotives ought to be in general use in freight service, to reduce the cost per ton-mile hauled. Economy of steam and saving in fuel are fundamentally necessary in transportation.

The real objections to compounds are the added weight, the complicated machinery, the expensive maintenance; and the delays, when repairs must be made on the road, subject the improved equipment to criticism by the operating department. Another point is that the engineman and fireman are already loaded with work, forcing the furnace, producing steam, and watching the track or signals in order to move the train with safety. Furthermore, most of them are not sufficiently good

mechanics to operate the improved machinery, and they are unfriendly to a type of locomotive which increases their burdens.

**Economy of compounds,** when new, is about 15 per cent. better than that of simple engines of the same weight, age, and service. In time the blows and the leaking of steam past the various packing rings of the valves and pistons, which are difficult to repair, reduce the economy of compounds. In all cases, the exhaust pressure of about 5 pounds must be maintained to cause a draft thru the fire.

Lack of economy on the down-hill trip offsets the better economy on the up-grade; and a uniform stretch has been found most advantageous.

Compound locomotives, with two cylinders, on the Chicago, Burlington & Quincy Railroad, when tested and compared with simple engines, were found to be 15 per cent. *more* economical in heavy freight service, and about 30 per cent. *less* economical in passenger service.

## MALLET LOCOMOTIVES.

Mallet, a French engineer, in 1876, furnished a practical design for a compound articulated locomotive with two sets of engines under one boiler. The Pennsylvania Railroad imported one, in 1889, built from designs of F. W. Webb, of the London and Northwestern Railway.

American Locomotive Company, in 1904, built for the Baltimore & Ohio Railroad the first one constructed in America.

About 100 Mallets were built prior to 1909, 162 in 1909, and 249 in 1910, or 5 per cent. of all locomotives built in these years.

Mallet compounds are now the largest steam locomotives. The articulated plan reduces the rigid wheel base and the individual weights of the moving and wearing parts, and distributes the weight on the roadbed. Mallet locomotives are frequently used in pushing service for freight on mountain grades. Lighter Mallets are used for road service on 1 per cent. grades.

The high-pressure cylinder on each side is located near the middle, and the low-pressure cylinder at the front end, of the locomotive. A cylinder ratio of about 2.4 is used. The speed of the heavy piston must be kept very low. The two trucks which support the boiler and cylinders are independent. Their drivers are independent; yet uniformity of tractive effort is obtained by the compensation of the steam pressures in the compound cylinders; if slipping occurs, even while operating simple, in starting, the low-pressure cylinder at once receives less mean effective steam pressure, and further slipping is prevented. The maximum tons per axle are 24 to 28. Enormous tractive efforts result from the combination of two sets of engines. Great heating surface is obtained in the long boiler.

High speed is not practical with Mallet compound locomotives as now designed, because there is a heavy leading truck swiveled on a pin behind its rear axle and carrying its load on a transverse shoe along which the load must be shifted for considerable distance to permit the radial movement of the truck; and this cannot be accomplished with safety at high speed or on rough or crooked track at medium speeds. Maintenance of the steam piping, heavy pistons, and of the mechanism increases most rapidly as the speed increases.

MALLET ARTICULATED COMPOUND LOCOMOTIVE DATA.

| Name of railroad. | Wheels. | No. | Cylinders, | Drivers. | Wt. on drivers. | Wt. of engine. | Total weight. | Heating surface. | Rigid base. |
|---|---|---|---|---|---|---|---|---|---|
| Baltimore&O. | 0-6-6-0 | 1 | 20 &32x32 | 57″ | 334,000 | 334,000 | 480,000 | 5585 | 10′-0″ |
| | 0-8-8-0 | 10 | 26 &41x32 | 56 | 454,000 | 454,000 | ....... | .... | ..... |
| Santa Fe..... | 2-8-8-2 | 4 | 26 &38x32 | 57 | 412,350 | 462,500 | 660,000 | 7839 | 15-0 |
| | 4-4-6-2 | 4 | 24 &38x28 | 73 | 268,000 | 376,500 | 610,000 | 4756 | 12-8 |
| | 2-8-8-2 | 30 | 26 &38x34 | 63 | 412,500 | 462,500 | 700,000 | 6621 | 16-6 |
| Southern Pacific | 2-8-8-2 | 18 | 26 &40x30 | 57 | 394,000 | 426,500 | 610,000 | 6393 | 15-0 |
| | 2-6-6-2 | 12 | 21.5&33x30 | 57 | 297,500 | 339,000 | 510,000 | 3906 | 10-0 |
| | 2-6-6-2 | 25 | 23 &35x32 | 55 | 350,000 | ........ | 518,000 | 5651 | ...... |
| Great Northern. | 2-6-6-2 | 25 | 21.5&33x32 | 55 | 316,000 | 355,000 | 504,000 | 5658 | 10-0 |
| | 2-6-6-2 | 45 | 20 &31x30 | 55 | 263,350 | 302,650 | 460,000 | 3906 | 9-10 |
| | 2-6-8-0 | 10 | 23 &35x32 | 55 | 360,000 | 378,000 | 526,000 | 5040 | 15-0 |
| | 2-6-6-2 | 16 | 21.5&33x32 | 55 | 313,500 | 350,000 | 500,000 | 5608 | 10-0 |
| Northern Pacific. | 2-6-6-2 | 6 | 20 &31x30 | 55 | 256,000 | 302,000 | ....... | 5586 | ...... |
| | 2-8-8-2 | 5 | 26 &40x30 | 57 | 404,000 | 438,000 | ........ | 6393 | ...... |
| | 0-8-8-0 | 3 | 25 &39x28 | 51 | 409,000 | 409,000 | ........ | 3433 | 14-3 |
| Erie R. R.... | 0-8-8-0 | 5 | 24.5&39x30 | 56 | 360,000 | 360,000 | 520,000 | 4905 | ...... |
| Norfolk & Western. | 2-8-8-2 | 5 | 24.5&39x30 | 56 | 360,000 | 390,000 | 540,000 | 5894 | 15-6 |
| C. B. & Q. | 2-6-6-2 | 10 | 23 &35x32 | 64 | 304,500 | 361,600 | 515,000 | 5094 | 11-6 |

**Reference:** Railway Age Gazette, April 21, 1911, p. 954.

**Baltimore & Ohio Railroad** used the first Mallet articulated locomotive built in America for pushing and hauling freight trains on the Connellsville Division.

Engine weight, 167 tons, is distributed over twelve 57-inch drivers, a 30-foot 6-inch wheel base, and a 10-foot rigid wheel base, resulting in minimum wear and tear on the roadway. Excessive weights are not concentrated on the wheel base. Center of gravity is high, so that the vibration of the locomotive, due to variations in surface alignment elevation, and curvature of track can be absorbed by the weight suspended over the driver springs. Sets of drivers do not slip at the same time. Operating and maintenance expense is 24 cents per mile. Muhlfeld, to New York R. R. Club, Feb., 1906; S. R. J., Feb. 24, 1906.

**Great Northern Railway** Mallet compound locomotives have a heating surface of 5658 square feet and a grate surface of 78 square feet. The weight, on 12 drivers, is 316,000 pounds; weight of engine, 355,000 pounds; weight of loaded tender, 149,000 pounds; total weight, 504,000 pounds. Length is 73 feet. Boiler tubes are 2.25 inches by 21.0 feet long. Two firemen are required. Steam pressure is 200 pounds.

The cylinders on each side are 21.5 inches and 33 inches, by 32-inch stroke. About 100 Mallets are used.

These locomotives were designed to push or pull an 800-ton train at 8.5 to 9 miles per hour up a 2.2 per cent. grade and around 10-degree curves.

Coal consumption, with 11,000 B. t. u. coal, is given as 4.5 pounds per h. p. hr.; to be compared with 5.5 for 2-cylinder compounds, and 6.33 for simple engines. As much coal may be used while standing as during the run. When the Mallet runs above or below the most economical speed, 11 m. p. h., the efficiency drops rapidly.

Horse power at the drawbar, at 9 m. p. h., is only 1260, or 5 h.p. per ton.

GREAT NORTHERN MALLET LOCOMOTIVE OPERATING CHARACTERISTICS.

| Miles per hour. | Drawbar pull. | Per cent. of pull. | Piston speed. | Drawbar h. p. | Trailing tons. |
|---|---|---|---|---|---|
| 0 | 55,000 | 85.0 | 0 | 0 | 880 |
| 5 | 54,000 | 84.0 | 169 | 700 | 880 |
| 9 | 52,500 | 81.7 | 304 | 1260 | 825 |
| 10 | 50,500 | 77.8 | 338 | 1345 | 815 |
| 15 | 44,500 | 69.0 | 507 | 1780 | 725 |
| 20 | 38,000 | 59.0 | 676 | 2050 | 570 |
| 25 | 30,500 | 47.5 | 845 | 2040 | 420 |
| 30 | 22,500 | 35.0 | 1014 | 1800 | 270 |
| 35 | 12,500 | 19.3 | 1183 | 1170 | 100 |
| 37 | 0 | 0 | 1250 | 0 | 0 |

Trailing tons include a 74-ton tender. Operation is at best efficiency on 2.2 per cent. grades, at 11 m. p. h., hauling 800-ton trailing load; but in service the speed is 9 to 7 m. p. h., and 900- to 1,000-ton trains are hauled. Toltz: New York Railroad Club, Dec., 1907.

Operation above 16 m. p. h. is dangerous. Increase of speed for long runs is obtained by reducing the trailing load.

Note the rapid decrease in drawbar pull as the speed increases.

The light load carried greatly increases the number of trains run. If the number of train-miles could be reduced one-half, by using more powerful engines, the net saving, with 6 trains per day per 100-mile division, of only 20 cents per train-mile, would be over $30,000 per year.

**Santa Fe** Mallets, built by Baldwin, are used to haul passenger trains, at express speed, over mountain grades of Southern California and Nevada. Boiler tubes, 294; length, 19 feet; diameter, 2.5 inches. Drivers are 73 inches. Engine wheel base is 52 feet. Feed water heater raises water temperature to 300 degrees. Superheater and reheater are used. Length of locomotive 105 feet. Fuel oil is burned.

**Southern Pacific** Mallet type locomotives are used on the Sacramento 140-mile division, over the Sierra Nevada Mountains. There is a 1.47 per cent. average grade for 83 miles, and a 2.4 per cent. ruling grade. Two Mallets, or four consolidation engines are used to haul a 2,000- to 2400-ton trailing load. The running speed is ordinarily 10 to 7 miles per hour. Fuel consumption is one gallon of oil per h. p. hour.

Wheel base; driving, 39 feet 4 inches, locomotive, 56 feet 7 inches, total, 83 feet 6 inches. Weight of engine, 426,000; on 56.5-inch drivers, 394,000; total 600,000. The cab is on the front end of Southern Pacific locomotives.

FIG. 24.—ATCHISON, TOPEKA & SANTA FE. MALLET ARTICULATED LOCOMOTIVE. Cylinders 24 and 38 by 28; heating surface 4756 square feet; weight 610,000 pounds, with 12,000 gallons of water and 4000 gallons of oil.

FIG. 25.—SOUTHERN PACIFIC MALLET ARTICULATED LOCOMOTIVE.

Cylinders, 26 and 40 inches by 30 inches. Locomotives are equipped with water heaters and superheaters. Boiler heating surface, 5173 square feet. Steam pressure, 200 pounds. The cut-offs at 12 miles per hour are 79 per cent. of full stroke.

## SOUTHERN PACIFIC MALLET LOCOMOTIVE OPERATING CHARACTERISTICS.

| Miles per hour. | Tractive power. | Piston speed. | Indicated h. p. | I.h.p. per cent. |
|---|---|---|---|---|
| 0 | 90,000 | 0 | 0 | 0 |
| 5 | 86,055 | 147.5 | 1147 | 45.1 |
| 10 | 77,136 | 297 | 2057 | 82.3 |
| 15 | 59,349 | 445.5 | 2373 | 94.9 |
| 18 | 51,796 | 535 | 2486 | 99.4 |
| 20 | 42,090 | 594 | 2245 | 89.8 |

Comparative tests of simple and Mallet locomotives of the consolidation type, on the Southern Pacific grade over the Sierra Nevada Mountains, were published in part in Railway Age Gazette, January 14, 1910, p. 81. The deductions from these service tests, comparing simple engine No. 2564 with Mallet compound No. 4001, are that on the 1.47 per cent. up-grade run, the Mallet was more economical than its competitor.

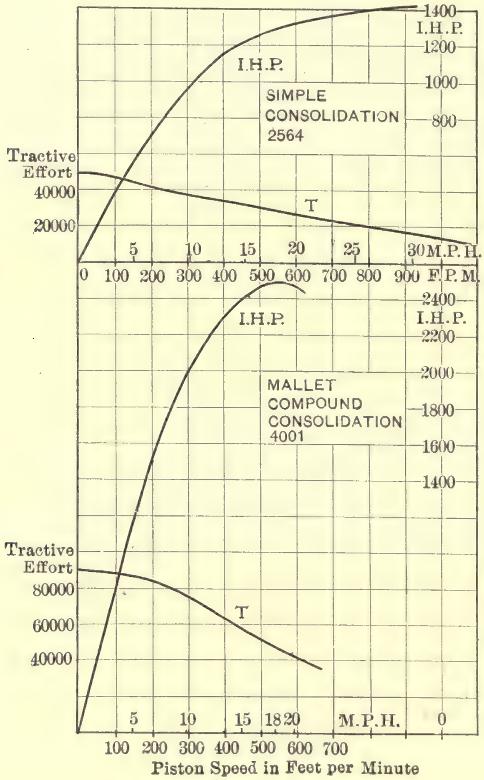


FIG. 26.—OPERATING CHARACTERISTICS OF SIMPLE AND MALLET COMPOUND LOCOMOTIVES. SOUTHERN PACIFIC CO.

Tractive effort is assumed at 29.4, plus 6.6, or 36 pounds per ton. Mechanical h. p. equals tonnage times tractive effort per ton, times speed in miles per hour, divided by 375.

Note the low speed, which increases the trainmen's wages; the light train, with a locomotive weighing 30 per cent. of the train weight; the maximum h. p., and the friction. The results of tests are discouraging.

SOUTHERN PACIFIC MALLET LOCOMOTIVE TESTS.

| Locomotive. | Mallet. | Simple. |
|---|---|---|
| Number | 4,001 | 2,564 |
| Pounds of steam evaporated | 365,500 | 197,183 |
| Pounds of steam evaporated f & a 212° | 445,000 | 237,500 |
| Average speed up 1.47% grade, m. p. h. | 9.91 | 13.42 |
| Weight of train | 1,006 | 478 |
| Weight of locomotive | 298 | 164 |
| Total weight of train, tons | 1,304 | 642 |
| Mechanical h. p. for the train | 1,248 | 833 |
| Indicated h. p. | 2,000 | 1,150 |
| Loss between indicated and drawbar power | 37.5% | 38.0% |
| Average number of hours, for 87-mile run | 8.75 | 6.47 |
| Pounds of steam per drawbar h. p. hour | 40.60 | 44.20 |
| Pounds of steam per indicated h. p. hour | 25.50 | 35.00 |

## STEAM TURBINE LOCOMOTIVES.

A turbine locomotive was built in 1909 by the North Bristol Locomotive Company of Glasgow. It has an ordinary locomotive boiler with a superheater. The steam which is generated is fed to a 3,000 r. p. m. impulse-type turbine. The latter is coupled to a direct-current, compound-wound, variable-voltage electric generator, which supplies current at from zero to 600 volts to 4 series-wound traction motors built on the driving axle of a double-truck locomotive. The exhaust steam from the turbine is condensed by an ejector condenser and the water so condensed, and free from oil, is used over and over again. Forced draft from a fan is used for the furnace. The service is express passenger work on the main line. Railway Age Gazette, July 22, 1910.

Another turbine locomotive, built in 1910 by a Milan firm, has two axles driven by a direct-action steam turbine. The blades are S-shaped and the motion is reversed by reversing the flow of steam. The drive is thru gearing, and speed changes are effected by means of a crown wheel which carries several rows of teeth. The economy at the rated load is 35 pounds of steam per h. p. hour.

The construction of these turbine locomotives shows clearly the desire of steam locomotive builders to avoid the reciprocating motion, to decrease the cylinder condensation and the relative consumption of fuel and water, and to produce more efficient results at the drawbar. The complication of a complete generating plant on each moving locomotive and the lack in capacity make it impractical.

## COST OF OPERATION OF STEAM LOCOMOTIVES.

**Operating expenses of steam locomotives** exceed one-third of the total operating expenses of steam railroad transportation. In general, the total cost of operation, from Interstate Commerce Reports, includes:

| | | |
|---|---|---|
| Maintenance of ways and structures .............. | .... | 22% |
| Maintenance of all equipment.................... | .... | 22% |
| of which the maintenance of locomotives is ...... | 11% | |
| Conducting transportation, ...................... | .... | 56% |
| of which engine and round house wages are...... | 11% | |
| of which fuel for locomotives alone is an added ... | 12% | |
| Totals....................... | 34% | 100% |

Where the traffic is heavy, on mountain grades, or where compound locomotives are used, the items of repairs and renewals of locomotives greatly exceed the average. Cost of coal is frequently high, and fuel expense greatly exceeds 12 per cent. Where water is bad, both fuel and repairs greatly exceed the above averages.

Expenses vary with the work done; up-hill or level, slow or time freight, express or ordinary passenger trains; and with the weather, management, etc. These elements change the performance and maintenance cost of steam locomotives on the same railroad. General data are valuable to show the averages, but managers and engineers find that, in practice, actual results are needed for each branch or division studied

The general data available are presented.

POUNDS OF COAL BURNED PER 1000 TON-MILE.

| Name of railroad. | Kind of service. | Coal per M. ton-miles. | Train tons. | Remarks and authority. |
|---|---|---|---|---|
| New York, New Haven | Express—Local..... | 335 | 527 | Murray, A. I. E. E., Jan. 25, |
| & Hartford (New York | Express............. | 194 | 314 | 1907, p. 148. |
| Division). | Freight............ | 169 | 931 | Year 1906. |
| Pennsylvania R. R...... | Ordinary freight.... | 60 | all | Good average on tests. |
| Chicago & Northwestern. | Freight............ | 255 to 280 | ...... | In winter. Henderson. |
| Chicago & Northwestern. | Freight............ | 185 to 210 | ...... | In summer. Henderson. |
| Chicago & Northwestern. | Freight............ | 226 | ...... | 2-year average. Henderson. |
| Delaware & Hudson .... | Freight pusher...... | 410 to 470 | 1431 | Ry. Age, May 27, 1910. |
| Rock Island............ | Fast passenger...... | 238 to 287 | 500 | Ry. Age, Jan. 6, 1911. |
| Great Northern......... | Mountain freight.... | 380 | 1050 | Consolidation. |
| Great Northern......... | Mountain freight.... | 251 | 1600 | Mallet compounds. |
| Great Northern......... | Level freight........ | 130 to 94 | 2000 | Illinois coal, Supt. M. P. |
| Great Northern......... | Freight—Mallet..... | 890 | 810 | 1.35% grade. Pomeroy. |
| Norfolk & Western...... | Freight—Mallet..... | 273 | 1500 | Ry. Age, May 19, 1911. |
| Chicago & Alton........ | Freight............ | ·230 | ...... | Ry. Age, June 16, 1911. |
| Northern Pacific ....... | Heavy passenger.... | 160 to 206 | 590 | Ry. Age, June 22, 1910. |
| | Heavy freight...... | 131 to 162 | 2050 | Ry. Age, June 22, 1910. |
| Six western roads....... | Freight............ | 215 | 1200 | October, 1909. |
| | | 235 | 1200 | November, 1909. |
| | | 270 | 1200 | December, 1909. |
| Ordinary simple loco- | Passenger on level .. | 250 | 500 | Author. |
| motives. | Freight on level..... | 150 | 1500 | Author. |
| | Freight on grades... | 250 | 1000 | Author. |

POUNDS OF COAL BURNED PER I. H. P. HOUR ON TEST.

| Railroad. | Service. | Coal. | Coal used, lbs. | Authority. |
|---|---|---|---|---|
| Mountain | Freight | San Coulle. | 12.3 to 14.0 | Pomeroy. |
| | Passenger and Ft. | Montana | 10.6 | A.I.E.E. |
| | Freight | High-grade. | 9.6 to 11.2 | November, 1909. |
| Mountain | Freight | Pittsburg | 4.0 to 8.0 | Road tests. |
| Mountain | Freight | Pittsburg | 6.0 to 12.0 | Road tests. |
| Ordinary | Suburban | Pittsburg | 6.5 to 7.0 | On test. |
| | Passenger | Pittsburg | 3.8 to 4.0 | On test. |
| | Freight | Pittsburg | 4.8 to 5.0 | On test. |
| New York, New | Passenger Express | Pittsburg | 4.06 to 4.37 | Murray. |
| Haven & Hart: | Passenger Local | Pittsburg | 4.68 to 4.61 | A.I.E.E., Jan. 25, 1907. |
| Pennsylvania | Freight | Pittsburg. | 4.35 to 4.71 | Ry. Age, June 21, 1910. |
| Electric | Electric plants | Pittsburg | 2.70 to 3.00 | Potter, 1905. |
| Ordinary | Turbine plants | Pittsburg | 2.00 to 2.20 | Guarantee. |

**Cost of coal burned per train-mile,** from such data as are available, approximates that for all trains in Massachusetts, 17 cents. Cost of coal for Mallet compounds in mountain service reaches 57 cents. It varies with stops per mile, weight, speed of train, temperature, etc.

Pounds of coal burned per locomotive-mile averages about 104 for passenger service, 208 for freight, 130 for mixed and non-revenue, 108 for switching, and about 150 for all service.

**Cost of operation per ton-mile** varies from 5 to 6 mils for ordinary freight service up to 17 mils for mountain-grade work. The cost varies with the character of service, grades, load, nature and amount of repairs, as well as the cost of labor, fuel, and supplies.

**Cost of maintenance and repairs per ton-mile** is 2.0 to 3.5 mils for ordinary freight locomotives, up to 7.1 for Mallet compounds.

**Cost of maintenance and repairs per locomotive-mile** for ordinary roads reporting to Railroad Commissions averages a little over 7 cents, but this excludes data for mountain divisions on which the cost of maintenance runs up as high as 57 cents. The road that has given efficiency methods the most thoro tryout, the Santa Fe, reported that the cost of repairs and renewals in 1910 was 10.75 cents.

**Cost of maintenance and repairs per locomotive-year** for three years prior to 1909 averaged about $2200, while for 1909 the average, from the annual reports of 15 common roads, was about $2600. Roads in the mountains average higher than those in the central states.

OPERATING EXPENSES FOR REPAIRS AND RENEWALS OF STEAM CARS AND LOCOMOTIVES.

| Name of railroad. | Per passenger car-mile. | Per freight car-mile. | Per locomotive-mile. | Per locomotive-year. |
|---|---|---|---|---|
| Boston & Maine | 1.38¢ | .66¢ | 6.15¢ | $......... |
| Boston & Albany | ........... | ........... | 14.60 | ........... |
| Delaware & Hudson | ........... | ........... | ........... | 2821. |
| New Haven | 1.35 | .66 | 7.93 | ........... |
| New York Central | 1.14 | .90 | 7.72 | 2128. |
| Lackawanna | 1.48 | .60 | 6.76 | 1732. |
| Central of New Jersey | 1.19 | 1.07 | 8.54 | ........... |
| Pennsylvania | 1.37 | .89 | 10.05 | 2694. |
| Baltimore & Ohio | .98 | .79 | 9.22 | 2889. |
| Lehigh Valley | 1.08 | .79 | 8.98 | 2185. |
| Erie | 1.28 | .76 | 10.56 | ........... |
| Wabash | .89 | .52 | 8.82 | ........... |
| Philadelphia & Reading | 3.70 | 1.33 | 10.78 | ........... |
| Toledo, St. Louis & Western | .73 | .23 | 8.47 | ........... |
| Chicago & Alton | .77 | .30 | 8.37 | ........... |
| Chicago & North Western | .84 | .51 | 6.30 | 2300. |
| Chicago, Burlington & Quincy | .76 | .77 | 7.65 | 2376. |
| Chicago, Milwaukee & St. Paul | .81 | .60 | 5.98 | 2361. |
| Chicago, Rock Island and Pacific | .84 | .69 | 8.27 | 2530. |
| Minneapolis & St. Louis | 1.08 | .80 | 6.88 | ........... |
| Atchison, Topeka & Santa Fe | 1.23 | .71 | 10.75 | 2541. |
| Denver & Rio Grande | ........... | ........... | ........... | 3156. |
| Illinois Central | ........... | ........... | 10.21 | 3085. |
| Mpls., St. P. & St. S. Marie | ........... | ........... | 7.72 | 2320. |
| Southern Pacific | ........... | ........... | ........... | 3343. |
| Union Pacific | ........... | ........... | ........... | 3593. |
| Northern Pacific | ........... | ........... | 8.21 | 1916. |
| Great Northern | ........... | ........... | 9.41 | 2240. |

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## CHAPTER III.

# ADVANTAGES OF ELECTRIC TRACTION FOR TRAINS.

### Outline.

**Basis.**

**Physical Advantages:**

Capacity, flexibility, simplicity, safety, reliability, improved service.

**Financial Advantages:**

*Gross Earnings Increased.*—Motive power characteristics, passenger traffic attracted, freight service of high-grade, freight service for trunk lines, termina traffic, delivery of freight and passengers, branch line electrification, frequent train service, suburban service.

*Operating Expenses Decreased.*—Maintenance of ways and equipment, wages and time saved, fuel and power, train-mile and ton-mile data.

**Investments decreased or increased.**

**Earning Power and Net Earnings.**

**By-products of Electrification.**

**Advantages in Business Depressions, and in Competition.**

**Social Advantages:**

Safety in travel, time saved, hard labor decreased, conservation of natural resources, cost of transportation, cost of living, esthetic enjoyments, social conditions improved.

**Objections to Electric Traction:**

Conservatism, crude presentation of situations, investments necessarily larger, complication, number of electric systems, interchangeability, danger, dependence on power plants, transimission losses, interference with signal lines, discard of steam locomotives; Illinois Central Railroad case, experimental for important service, a luxury, the financial problem.

**Literature:**

Physical advantages of electric traction, financial data on operation.

## CHAPTER III.

# ADVANTAGES OF ELECTRIC TRACTION FOR TRAINS.

### BASIS.

The advantages of electricity for traction form the basis of electric railway economics. These advantages will now be outlined in a systematic manner for reference, and to facilitate a study and comparison of the operating features of steam and electricity for train haulage.

### PHYSICAL ADVANTAGES.

All of the advantages of electric traction depend primarily on the application of the physical characteristics of electric power. This application of electric power requires the utilization of the heat of burning fuel, or the energy of falling water, as a primary source of energy, which is then converted into electric power, and transmitted by wires over long distances to motors which propel the trains on the railway division. This plan is now used in modern transportation, and it provides:

**Capacity, flexibility, simplicity, safety, and reliability**; and an improved service produces two definite results:

**Financial advantages and social advantages.**

### CAPACITY.

Ample capacity is a very useful physical advantage in transportation. In dealing with heavier traffic, capacity must be increased in every direction, in the motive power, and also in the efficient use of the cars, tracks, and terminals.

Capacity in electric motor power is obtained from central power stations, from which energy is transmitted in large amounts, over great distances, to electric motors which have great power per unit of weight, and which are able to withstand heavy overloads.

**Electric motive power** for railway train service means ample drawbar pull, and good speed. Electric motors on the locomotive frame, or distributed on the passenger-car trucks, provide the maximum possible tractive effort for heavy tonnage, or for rapid acceleration.

The hauling capacity of important roads having frequent and heavy trains is often limited by the long tunnels, the heavy grades, the support for the roadbed, the single track, and the terminal facilities.

The tendency of modern methods of freight transportation is to use cars in 2000- to 3500-ton trains. In ore and coal trains, the rated load of each car runs up to 140,000 pounds with the usual 10 per cent. overload allowed under M. C. B. rules. The drawbar pull for heavy trains on the up-grades is enormous. Slow speed is the present handicap and,

while a high speed is not desired, a moderate, sustained speed on the up-grades has economic advantages.

Passenger and mail coaches of steel now weigh 50 to 70 tons each. The best steam railroad locomotive, of the Pacific type, weighing 200 tons, with 4200 square feet of heating surface, 22x28 cylinders, and 79-inch drivers, as used on the "Twentieth Century Limited," lacks in capacity, and can haul only six (6) steel cars at 60 miles per hour. (Railway Age: Editorial and data beginning Dec. 24, 1909.)

Examples are given to illustrate and to prove that ample capacity is available with electric traction.

**New York Central Railroad,** in and near New York City, uses electric traction. The important results of this notable electrification were, an increase in the length and weight of the trains, an increase in the number of trains, an increase in the schedule speed, the ability to use locomotives with greater hauling capacity and speed, and therefore an increase in the capacity of the terminal. The capacity could not be increased to the satisfaction of the stockholders and the public by using more and heavier steam locomotives. Wilgus, St. Ry. Journ., Oct. 8, 1904.

**Manhattan Elevated Railroad,** of New York, was formerly, in point of earnings, one of the largest steam roads in the country. Steam locomotives hauled, at most, 4- or 5-car trains at 11 to 10 miles per hour. The elevated structure could not be rebuilt or increased in strength; nor was there any way of improving the train service and capacity except by a change in motive power. Electric power was introduced in 1902, the installation being completed in June, 1903. The substitution of electric power made possible an increase of 33 per cent. in the carrying capacity of the road, as was proved by the actual increase in mileage and in passenger traffic. The electric trains now have 6 or 7 cars, running at 15.0 to 13.5 miles per hour. Incidentally, between 1901 and 1904, the operating expenses dropped from 55 to 45 per cent., and the traffic which had been lost, because of competition, was regained.

**New York Subway** of the Interboro Rapid Transit Company is a four-track road. Ten-car passenger trains are now dispatched on the local and the express tracks on 108-second headway. About 666 cars pass a given point per hour in each direction. Electric-pneumatic brakes stop the train, running at a speed of 40 miles per hour, in a distance of 365 feet. Each 10-car train is equipped with motors equal to 3200 h. p. or more than twice the horse power used on steam locomotive-hauled trains. The number of seats per train is 500 and the service requires platforms of the full train length, 510 feet, and three side doors per car.

Steam railroads cannot even approach these results. Illinois Central Railroad, at Chicago, has less than 1000 cars in 24 hours.

**Long Island Railroad** electrification work "greatly increased the capacity of the line, and especially that of the Brooklyn terminal, which could not be operated by steam up to its present capacity." Gibbs.

"In the average steam terminal it was rarely possible to place, load, and dispatch more than 5 or 6 trains per hour from any track. But with multiple-unit equipment, it was possible to increase this to 8 or 10 trains per hour, the equipment of some 4 or 5 of them being that of trains that had come in and unloaded their passengers on that track. A multiple-unit shifting crew makes but half the number of movements as compared with steam service and, with a crew of two, easily accomplishes the work of two yard engines." McCrea, General Superintendent.

**Great Northern Railway,** in 1909, equipped its main line thru the Cascade tunnel with electric power, for the purpose of avoiding the smoke and the gases which retarded traffic thru the tunnel, and the capacity of the Cascade Division.

"The great increase in the speed of trains with electric traction and the consequent increase in the capacity of a single track will operate to postpone for a long time the necessity of double tracking. This double tracking in the mountains is a very expensive piece of business, and the saving alone will, in some cases, more than offset the cost of electrical equipment." Hutchinson, before A. I. E. E., Nov., 1909.

**Lancashire and Yorkshire Railway** of England, in 1904, electrified its Liverpool-Southport passenger branch. The results were:

Thirty steam locomotives with tenders, and 152 coaches, having a seating capacity of 5084, were replaced by

Thirty-eight 60-foot electric motor cars, and 53 coaches, having a seating capacity of 5814.

Frequency of passenger trains was doubled; acceleration and average speed were increased; and two of the four tracks, on the section used for passenger service, were appropriated for freight service. The number of passengers increased 14 per cent., yet the ton-mileage *decreased* 12 per cent.

"The electrification of the line from Liverpool to Southport, 26 miles, will double the carrying capacity of the line and also practically double the terminal accommodation." J. A. F. Aspinwall, Manager.

**North-Eastern Railway,** out of Newcastle, England, 82 miles of track, with an average distance between station stops of 1.25 miles, was electrified in 1904. Motor cars are used for freight and for passenger haulage. Train haulage on this road has since increased about 100 per cent., yet the ton-mileage has actually decreased.

Much more work is now done at the terminal stations, as there are no engines to attach or detach. Trains are dispatched at one-minute intervals. Signal operations were reduced about one-half.

Higher acceleration was realized which decreased the running time between stations 15 to 19 per cent. It would have been impossible to carry by the steam service the number of passengers now electrically conveyed. Harrison, to British Inst. of Civil Engineers, November, 1909.

**Capacity Can be Gained without Electric Operation.**—However, that may require an increase in the weight and heating surface of steam locomotives to increase the drawbar pull and the accelerating rate; or a long and wasteful cut-off in the steam cylinder to get faster acceleration or higher speed. It may require the use of double-end, tank types, or concentrated weights in steam locomotives; an increase in the rolling stock; an increase in the number of trains; or heavy expenditures for double tracking and grade reduction. Expenses are increased by the unnecessary or undesirable increase in the ton-mileage of the steam equipment, and often the increased operating expenses and interest charges cannot be balanced by an increase in the net earnings.

### FLEXIBILITY.

Flexibility is a valuable physical advantage, since it contributes to the economic superiority of electric traction. Examples are reviewed:

Electric locomotives in 1000-h.p. units are used to haul ordinary 250-ton trains, while two coupled locomotive-units are used for heavy 550-ton trains in thru train service (New Haven Railroad). This is often done with steam locomotives, but not to advantage, for it is hard for 2 enginemen and 2 firemen to control 2 independent steam locomotives. The 2 electric locomotive units are controlled from the front cab by one operator. Again, two 66-ton coupled electric locomotives are operated as one unit for 1000-ton freight trains, while one 66-ton electric locomotive is used for a 200- to 350-ton passenger train (Grand Trunk Railway). Again, one type and size of electric locomotive is often inherently suited for either passenger or freight service. (New Haven 1300-h. p. freight locomotives).

"On the New York Central electrification one of the results was to replace the dozen types and sizes of locomotives formerly used within the territory determined for electric operation by a single type and size of electric locomotive with such a capacity and capable of such control as to meet all the requirements of speed and power, whether switching in the yards or hauling the heaviest trains at schedule speed." Sprague.

Electric locomotive frames, superstructures, and wheels are symmetrical, which provides flexibility in operation and eliminates the great expense at the turn-table. With steam locomotives the coal and water supply must trail, for safety. With electric equipment, the most advantageous use of cars, tracks, and terminals becomes possible, particularly for concentrated working of express and freight service.

Motor-car trains provide for absolute flexibility of train operation.

Controllers of the automatic type may be located for use at either end of each electric locomotive, motor-car, or coach—whichever happens to come at the head of the train. Similarity of equipment of motor-cars is such that they may be coupled up in any combination, whatever the nature of the service or length of the train. Head- and tail-switching are abolished. Electrically controlled trains, by reason of the mechanical flexibility are economical, and are adapted to frequent service and to rapid changes in the traffic.

## SIMPLICITY.

Simplicity is evident. Compare the moving parts, the rotating motor armature in one case, and the eccentric strap, rocker arm, valve gear, reciprocating valves and stems, pistons, piston rods, cranks, and unbalanced driving wheels in the other case. Boilers and furnaces are absent in electric trains. Fewer parts reduce the wear, tear, and maintenance.

## SAFETY.

Safety to life and property, and reliable service, are promoted by electric railway transportation. Simplicity and safety in the operation of electric locomotives and of the motor-car train are discussed at length under the following headings:

Design of electric motors avoids track pounding.
Control circuits prevent accidents.
Automatic devices safeguard operation.
Speed may be decreased with safety, or limited, by design.
Long wheel bases are avoided on trucks.
Vigorous tests are easily made.
Regeneration of energy in braking prevents accidents.
Tunnels are made safer.
Boilers are avoided.
Fire risk to property is decreased.
Exhaust steam and smoke are absent.
Enginemen are not distracted with other duties.
Electric meters assist in operation.
Weights are not excessive, so as to spread rails.

**Design of electric motors** is such that there is an absence of that track pounding which in steam locomotives is caused by the reciprocating motion and unbalanced forces. After a single trip of the Pennsylvania 18-hour, New York to Chicago train, 20 broken rails were reported. This did not reflect so much on the integrity of the rail manufacturer, or upon the design of the rail section or weight, as on a characteristic of the steam locomotives.

The distribution of weight and the uniformity of the tractive effort in

electric motors contribute to safety on the roadbed, curves, and bridges. Broken rails and driver axles, common sources of wrecks, are decreased.

**Control circuits** prevent accidents. The section terminals in the regular signal towers of the New Haven and other electric railroads are 2 to 3 miles apart, and are placed in charge of signal men. This introduces a new element in the safe running of trains, because a signal man can stop a train by cutting off power at his end of the section and telephoning the signal man at the other end to do the same. Power circuits can be opened to prevent accidents by providing distant control of circuits at the signal stations, substations, or power plant.

**Automatic devices** are provided on the controllers in the cabs of electric trains to shut off the power instantly, if the engineman for any reason—death, collision, etc.—removes his hand from the control handle. This is a further safeguard to the traveling public.

The accelerating rate is controlled automatically, independent of the operator. Controllers are often so arranged that the train cannot be started if the air reservoirs have not sufficient pressure for braking. Other devices automatically shut off the power and apply the brakes if the train passes its signals. Elec. Ry. Journ., March 5, 1910, p. 419.

**Speed may be increased safely** as was proved by Berlin-Zossen tests, where speeds of 130 m. p. h. were attained. In motor controllers, speed limiting devices are in common service. Synchronous motors have a fixed maximum speed.

**Long rigid wheel bases** are not required, and thus the curves are taken smoothly, and safely, at high speed.

**Vigorous tests** to detect troubles on electric power equipment can be made with ease, and in a simple way, by using a voltage 3 or 4 times the normal.

**Regeneration of energy** provides for electric braking on down-grades. Electric trains in the mountains are so controlled, regularly, and not in the emergency; and the air brakes are used for reserve. It is very advantageous to run down the grade with the train under full control. Air-braking in the mountains causes shoes to wear out quickly, defective brakes, brake-rigging, and loosened wheel rims. A decrease in the number and in the cost of wrecks is important.

**Tunnels** are made safer with electric power. This is the universal experience. The walls are lighted and whitewashed; the rails are not greasy or slippery from condensed steam; the smoke and gases do not suffocate; and little danger exists if the train stalls. Long tunnels may be operated as safely as short ones. Electric locomotive operation on the steepest and longest tunnel grades is practical. Enginemen and trainmen have confidence in electric power, and the long mountain tunnel has lost its terrors.

Air brakes, or electric brakes, can be used on electric trains on heavy grades in tunnels where formerly it was necessary to use hand brakes. With a break-in-two of a steam train in a tunnel, the air could not be released or the train recoupled, because the trainmen were suffocated by the locomotive gases.

**Boilers** present dangers from furnaces, high pressures, explosions, scaldings, water in cylinders, damage from reciprocating pistons and mechanism, which are avoided in electric trains.

**Fire risk** is decreased and loss is avoided with electric traction as there are no sparks to set fire to valuable forests, buildings, docks, snow sheds, grain and hay, freight cars, and their contents. There is less risk of fire in case of a wreck.

**Exhaust steam clouds,** the cause of many expensive railroad accidents, following the inability of the lookout to see the signals and the track, in the tunnel or in the open, are absent in electric traction.

**Enginemen of electric trains** have clearer judgment. They are placed in a cool and comfortable situation. The view between the cab and the track and signals in foggy weather is clearer. Electrical control allows them to put their mind on the safe piloting of the train, without the distraction due to steam-power generation and the care of mechanism. The importance of this is evident to one who knows the strain on an engineman in watching for signals and listening to the train motion. Safety is also promoted by the quietness which is due to the absence of exhaust steam, the pounding of reciprocating pistons, and unbalanced drivers. Judgment of enginemen of electric trains is thus clearer in emergencies.

**Electric meters** assist in intelligent operation of the motive power and this is recognized as a great advantage accompanying electric traction. The exact service performance of each electric generating unit at the station, and of each feeder section, is obtained by a glance at indicating meters, or a study of curve-drawn power sheets, and the integrated record of the energy supplied. Meters in the cab indicate the h. p. which is supplied to the railway motors. A glance at the meter shows the rate at which the train is accelerating. Tests are not needed; the facts are instantly apparent, and the engineman is posted, is forewarned, and acts intelligently to remove the cause of any defect. He gains confidence while the equipment is in operation.

Enginemen on the electric locomotives of the New York Central, the New Haven, the Grand Trunk, and other roads, use the indicating meters to advantage, and particularly so if the overload is great. When the snow is deep and the tractive effort is high, the meter is particularly advantageous; and if trouble is suspected, the meters in the cab furnish valuable information. Steam locomotive enginemen, by long experience

under set conditions, know the drawbar pull and the h.p. developed and the boiler overload, but only in a general way.

**Weights are not excessive** with electric traction. Weight per foot of total wheel base varies from 6000 to 7000 pounds and is only 10 per cent. less than in steam locomotive practice; but the total weight of an electric locomotive is about one-half that of a steam locomotive per h. p. developed. In motor-car trains the weight is only one-third, and its distribution is excellent. The decreased strains promote safety.

## RELIABILITY.

Reliability in electric traction results from simplicity. Reliability of service has been radically increased by electric roads, particularly on trunk lines and in terminal service. This fact is particularly noticeable in times of snow storms and extremely cold weather. Duplication of boilers, generators, transmissions, and motors is necessary for reliability, but generally these do not add to the total cost of the equipment needed. A single motor of many in a train may burn out, yet not affect the service. Controllers are complicated yet are wonderfully reliable.

Results on electrified roads furnish this evidence:

Manhattan Elevated Railroad was a good example of a well managed steam road from 1872 to 1902. Records fairly compared show double the car-mileage per train-minute delay, with electric power. "The delays in traffic with electric power were less than 40 per cent. as numerous as when steam power was used." Stillwell.

New York Central records for the New York terminal service for four months, July, August, September, and October, 1908, show a total train delay of only 160 minutes.

New York Central records for 1909 state that 177,802 trains were handled by electric motors with a total train-minute delay of 36,563, or an average detention of 12 seconds per train, a record unequalled in the history of railroading.

"New York Central electrical service during 1908 showed there was not one minute delay because of the power station, substations, or transmission lines. The delays from feeders were 7 train minutes; from third-rail, 150 train minutes; from electric locomotives, 400 train minutes, out of a total locomotive mileage of 1,000,000 and a total multiple-unit train mileage of over 3,500,000. The average delay was 1 minute for each 3,000 train miles travelled. The average train movements per day in and out of the Grand Central Station was 450." Katte, before New York Railroad Club, March 19, 1909.

Long Island Railroad records: "Motor-car miles per detention, 9514."

West Jersey & Seashore: "Motor-car miles per detention, 6118."

Interborough Rapid Transit records, noted in St. Ry. Journ., March 28, 1908, show that an average of 257,759 car-miles were operated per 1-minute delay in power supply on the Manhattan or Elevated division. Figures showing such a reliability of power supply have never been produced by any steam railroad.

Hudson and Manhattan Railroad motor-car train service between New York, Jersey City, and Hoboken, averages about 72,000 car miles per 1-minute delay. The service is severe, with the recognized disadvantage of underground operation, a headway during rush hours of 60 seconds, 2200 trains per day on a double track, more passengers per car-mile than any rapid transit line, numerous sharp curves, and grades from 2.0 to 4.5 per cent.

Grand Trunk Railway locomotives are in severe tunnel-grade service for freight and passenger traffic between Port Huron and Sarnia, and each makes over 100 miles per day. Records recently given by the electrical engineer to the writer show one 8-minute delay in one year.

New York, New Haven Hartford records made for the year 1910 show that the electric locomotive failures per train-mile were only two-thirds as frequent as those of the former and existing steam locomotives. The average mileage per detention, many of which only slightly exceeded one minute duration and include all mechanical trouble, is 2 to 3 times better than with steam locomotives.

The reputation of a railroad for reliability of schedule speed, and for safety, determines the amount of traffic, in some measure. The weak roads, the ones with inferior power and delayed trains, are known and avoided. Reliable service and ample capacity are determining features in passenger and freight haulage, when there is a choice of routes.

**Improved service** results from these physical advantages—capacity, flexibility, simplicity, safety, and reliability.

That electric traction can meet all the physical requirements for train service is now an established fact.

### FINANCIAL ADVANTAGES.

The physical characteristics outlined contribute directly to definite commercial and economical advantages. Electric traction, however, always necessitates a large outlay of capital, and therefore the increased capital charges must be met by a combination of increased gross earnings and decreased operating expenses.

### GROSS EARNINGS INCREASED.

The adoption of electric traction for train service has generally increased the gross earnings. Electric roads have increased their business per mile of track more rapidly than other roads. Patronage has been

attracted and traffic has been developed, so that electrically operated trains now monopolize the suburban traffic, and without changes in fares and rates secure the interstate business and local freight haulage.

Gross earnings are increased when the *facilities* offered, *methods* of transportation, and *rates* are satisfactory to shippers and to travelers.

In general, it is more practical in railway transportation, electric or steam, to increase the net earnings by an increase in gross earnings than by a reduction in the operating expenses.

**Motive power characteristics** of any road influence the amount of traffic or business. The railroad which handles the heaviest freight- and passenger-train service most advantageously will find that preference is given to it, and that business is routed via its road. Electric power can provide for increased train loads, with the same or higher speed, and facilitate the handling at terminals; and thus the profits on the increased or competitive business may overbalance the increased interest charges for electrification.

Electric roads certainly have *acquired* and *retained* traffic, and are progressing rapidly in train haulage.

**Railways create their own business** and this is increased when the traffic is attracted by the motive power, excellent operative results, rapid acceleration, high schedule speeds, safety, cleanliness, increased conveniences, and comfort.

**Passenger traffic** is attracted by electric trains and to such an extent that, with equal fares, speed, and equipment, the public seems to even discriminate in favor of electric motive power wherever it can be obtained.

**Freight service** of a high grade is provided by electric trains, and is used by manufacturers, shippers, and merchants. Ample motive power, rapid work, and convenient transportation facilities induce traffic. These advantages are steadily increasing the amount of the fast or time freight business of electric railways. With the heaviest traffic, and on grades, the freight service is neither bunched nor throttled, because, with ample central station capacity, it is not necessary to reduce the loads or the speed, or to delay the switching. Freight traffic is thus expedited.

Electric roads have now equipped freight cars with electric motors on the trucks; and these cars, when loaded, are hauled in three-car or longer trains for the local service on lines 30 to 100 miles long. Box cars with motors on axles are loaded with freight, and haul other cars. Hundreds of 30- to 50-ton locomotives have been put in service.

**Trunk lines in freight service** can increase their gross earnings by adopting electric power. The laws of induced traffic apply equally well to trunk-line freight and to branch-line passenger traffic.

The present method of operation, with steam traction, calls for a

train load which the locomotive can just drag up the ruling grade. The locomotive works overloaded, at 1/2 to 3/4 stroke; it runs at 6 to 12 miles per hour; it delays all overtaking and opposing traffic; and, during 30 to 80 per cent. of the time, it is held at sidings, to avoid other traffic. The result is not only waste of fuel, high maintenance per ton-mile, waste of time of men, but a loss of time by other trains, in efficient use of track, procrastination in freight delivery, extra investments, car and locomotive shortage, dissatisfied shippers, and disappointment; but a heavy tonnage per train appears on the office records.

At present freight service is not satisfactory to shippers, and gross earnings, or business offered, are reduced when longer, slower trains are operated. The capacity of the road in relation to the rest of the system is restricted by the opposing freight trains, particularly in stormy weather.

The value of a reduction in train-miles is evident, provided speed is well maintained. Expenses of operation are per train-mile, and amount to 50 to 60 cents for transportation expense, exclusive of fixed charges, office and general expense; so that on a 100-mile division with 10 trains per day, or 3,650,000 train-miles per year, the expenses are about $1,825,000 per year. Any small reduction in train-miles by more powerful motive power makes the capitalized saving a large item.

Low-grade freight service may be considered as traffic well established and somewhat set in its ways. In this service, longer trains can be hauled by electric power, to reduce the expense per ton-mile hauled.

Electric locomotives improve the present methods of operation, and haul heavier tonnage at a higher schedule speed. Traffic is not delayed, and congestion is prevented. The equipment may be limited, but worked efficiently. When tonnage is carried at higher speed, the shipper remembers which road delivers the goods on time—winter and summer—and has efficient and powerful equipment.

**Traffic can be induced** because most traffic is competitive. Traffic is given to the trunk line with adequate motive power, electric or steam. New business and manufacturing is started along a trunk line, when its reputation for service is good. Business is attracted by service.

The central idea is to create new business, and to increase the gross earnings by simply providing better service, and higher speed, for the tonnage. The greatest field for electric power is in heavy steady freight traffic, because the amount of business, and the economies to be effected in fuel and labor, are larger than that with the fluctuating passenger service alone.

**Terminal traffic** is made attractive by the use of electric locomotives and motor-car trains. Flexibility is also available for freight terminal service. The yards can be cleared as the freight accumulates; and thus the best facilities for concentrated working at congested terminals are

provided. Extra movements are not required for switching and coupling; the acceleration rates used save time; signal operations are reduced one-half; and complication is avoided.

Terminal traffic is ordinarily dense; real estate is expensive, and trackage is limited. Minutes or even seconds saved, per train, by electric power may therefore be important, in order that the limited trackage may be used efficiently.

Boston & Albany Railroad has considered electric traction for its Boston terminal. A. H. Smith, Vice-president, reports that if electricity were used as a motive power there would be an increase of 50 per cent. in terminal facilities; and incidentally, the cost of rolling stock would be reduced 20 per cent.; the running cost decreased 30 to 50 per cent.; and the repairs to rolling stock reduced from 10 to 50 per cent. Report to Massachusetts Board of Railroad Commissioners, 1908, on Electrification of Boston Steam Terminals.

Boston Transit Commission, George C. Crocker, Chairman, reporting to the Legislature in April, 1911, contended that the increased traffic certain to follow the adoption of electricity within the Boston district would render the change financially profitable to the railroads. The total traffic at the steam railroad terminals at Boston exceeds 60,000,000 passengers per year—or three times the terminal traffic at the Grand Central Station at New York. An increase of 20 per cent in the traffic, assuming that each passenger travels ten miles within the electrical district, at 1.6c. per mile, would add $2,000,000 to the gross earnings the first year, and more thereafter, which would pay 5 per cent, on the estimated cost of $40,000,000 required to electrify all the lines in the metropolitan district. The saving in real estate and its advantageous use would add greatly to the gross earnings.

Grand Central Station terminal at New York, with steam service, had a car capacity of 366, while with electric service it will have 1149. The terminal track mileage is 32 miles, with 46 tracks against platforms. The new terminal has 46.2 acres on the main level and 23.6 on the suburban level. Electricity as a motive power changed old conditions, and it is now only necessary to provide sufficient head room for the trains.

Terminal capacity of most railroads is limited. Many railroads have already adopted electric power at terminals to increase their gross earnings. Congestion has been derceased, and train movements simplified. The matter is important because the cost of increasing terminal space and facilities is enormous, the cost being decidedly greater than the entire cost of electrification of existing terminals.

Gross earnings are increased at terminals when ample capacity and increased drawbar pull per pound in the electric motive power allow heavier tonnage and faster schedule speeds than is possible in steam

traction. Electric service provides for much greater ton-mileage without an increase in track, terminals, or car equipment. The improvement is of a magnitude and character impossible with steam service. The increased facility for handling business always results in augmented traffic and increased use of the given trackage, roadbed and equipment. The efficiency of a road is proportional to the ton-miles of freight, or the passenger car-miles hauled in a unit of time.

Terminal yardage in some roads is ample; and additional cars would mean congestion of traffic. What is wanted to prevent congestion is not more trackage, or more locomotives, but efficient switching service. With electric traction a high degree of efficiency in this respect is possible.

**Delivery of freight and passengers** is facilitated and oftentimes is made practical only with electric traction. Convenient terminals are important for long distance traffic; and they are very advantageous for short-haul traffic or rapid transit near large cities, since the convenience of the passenger and freight terminals increases the gross earnings. Interurban electric cars which pass thru city business districts now carry the bulk of the short-haul passenger traffic and much of the light freight. Problems concernings grade-crossings, terminals sites, and the best use of real estate are often to be solved by the use of a subway leading to a convenient terminal. Good facilities for passenger and freight delivery, especially where the traffic is competitive, are paying investments.

With steam traction, passengers are often carried to a terminal very far from the business and resident center of the city, and a ferry trip, a trolley transfer, or a long walk is required. Electric trains make possible a more convenient and less expensive terminal, and this is especially true if a subway, tunnel, or elevated approach is utilized.

**Branch line electrification** is often advantageous because with electric power on the main line, its use on the branch line, with electricity supplied from the central power stations to locomotives and to motor-car trains, is practical. Freight or passenger cars, wholly or partly equipped with electric motors, may be attached to, or taken from, the main thru train at a junction point. This plan increases largely the facilities for service, induces new traffic, and results in decreased cost of operation per train-mile on the branch line.

**Joint use of tracks** by both steam and electric trains is now common on the same right-of-way, and without embarrassment to either. The track, the terminals, the labor, the management, and the capital are thus utilized to increase the gross earnings.

**Frequent train service** is commercially practical with electric traction, and results in increased earnings. Ordinary steam railroad traffic must for economy of operation be concentrated in several heavy trains per day.

In steam service, the irreducible elements entering into train-mile cost are so large that, in practice, a passenger train must earn at least 50 cents per train-mile. In electric service, the cost per train-mile is radically reduced. Frequent freight train service is furnished without a proportional increase in expense and, for times of light traffic, short freight trains may be run with economy. This reduction in the cost of transportation makes possible a more frequent freight and passenger service, to increase the gross earnings.

In ordinary long-distance electric railway traffic, the method of operation is to use many short or long trains for first-class fast-freight traffic, and to run them at frequent intervals, instead of long trains at infrequent intervals. This is the most economical method in a small electric railway, but it is not essential with 20 or more trains each way per day.

The load on the electric power station furnishing service for *frequent* trains with long runs is much more uniform or steady than for infrequent service; and the operating expenses and amount of equipment are thereby reduced per ton-, or per train-mile, so that the cost of power is not necessarily greater than for less frequent, longer trains operated with steam locomotives. In practice, it is found that frequent passenger train service and the steady pull of the thru freight trains, on long lines, provides a most desirable load on the power station.

**Suburban traffic earnings** increase in amount and profit, and growth of suburban districts results when electric power is furnished from a central station for frequent train service. Suburban business is generally competitive business. It is steady and dependable; it is not affected by hard times, and requires small organization.

There is at present almost universal complaint on the part of steam roads that subrban service does not pay. On the other hand, it is universally accepted as a fact that electric suburban lines on a private right-of-way, with termini in large cities, pay handsomely, when in the hands of skilfully managed electric railway organizations. Steam railroads are now seldom willing to give up their alleged money-losing suburban service to an electric railway lessee; nor should they, in the light of recent electric railroad experience.

"Economy of operation derived from the running of short and frequent trains will benefit the public and the railroads. Short, frequent trains are exactly what the suburbanite needs. The flexibility of electric power will give more frequent service at reduced cost; the elimination of switching will be advantageous, and overcrowding will be diminished. With more frequent and cleanly service, population will be attracted to the suburban territory as it is not under the present regime. The traffic will be generally increased by the introduction of electric service." Report of United Improvement Association, Boston, 1910.

Suburban lines of steam railroads will certainly be gradually converted to electrical operation, to get more satisfactory results for the stockholders and for the public. The work already done, and the economic results thereof, justify this statement.

Electric trains on city streets radiating from our large cities will take the business away from the steam roads until they in turn use modern motive power for suburban train service extending from 10 to 30 miles out from cities; yet the steam railroad, with its superior right-of-way, requires a much smaller investment to attract this business, or to regain what has been lost. A commuter on the train of an electrified steam road can be assured of a comfortable seat, and decidedly better service.

"*The present cost of doing suburban business upon our lines is excessive, it is only by largely increasing the volume that we can hope for remuneration. To handle the same as at present is a burden, and to increase the volume and reduce the cost thru the substitution of electricity for steam seems the only solution.*" President Mellin, of New York, New Haven & Hartford Railroad in annual report, June, 1904.

## FINANCIAL ADVANTAGES—OPERATING EXPENSES DECREASED.

Statistics on classification and proportion are first presented.

OPERATING EXPENSES OF STEAM RAILROADS OF THE UNITED STATES.

| Interstate commerce commission report for Year ending June 30. | 1899 | 1908 |
|---|---|---|
| Maintenance of way and structures: | | |
| Repairs of roadway | 10.720% | 10.834% |
| Renewals of rails | 1.322 | 1.145 |
| Renewals of ties | 2.901 | 2.388 |
| Repairs and renewals of bridges, culverts | 2.374 | 1.984 |
| Repairs and renewals of fences, crossings | .487 | .407 |
| Repairs and renewals of buildings, fixtures | 2.181 | 2.288 |
| Repairs and renewals of docks and wharves | .254 | .224 |
| Repairs and renewals of telegraph | .142 | .211 |
| Other expenses | .472 | .175 |
| Maintenance of equipment: | | |
| Superintendence | .632 | .567 |
| Repairs and renewals of locomotives | 6.208 | 7.664 |
| Repairs and renewals of passenger cars | 2.164 | 1.932 |
| Repairs and renewals of freight cars | 7.038 | 9.114 |
| Repairs and renewals of work cars | .210 | .276 |
| Repairs and renewals of marine equipment, | .247 | .196 |
| Repairs and renewals of shop machinery | .512 | .657 |
| Other expenses | .584 | .658 |

OPERATING EXPENSES OF STEAM RAILROADS OF THE UNITED STATES
Continued.

| Interstate commerce commission report for Year ending June 30. | 1899 | 1908 |
|---|---|---|
| Conducting transportation: | | |
| Superintendence | 1.767 | 1.761 |
| Engine and roundhouse men | 9.690 | 9.366 |
| Fuel for locomotives | 9.478 | 11.471 |
| Water supply for locomotives | .619 | .670 |
| Other supplies for locomotives | .536 | .631 |
| Train service | 7.583 | 6.389 |
| Train supplies and expenses | 1.527 | 1.597 |
| Switchmen, flagmen, and watchmen | 4.149 | 4.509 |
| Telegraph expenses | 1.906 | 1.763 |
| Station service and supplies | 8.206 | 7.022 |
| Car mileage—balance | 2.010 | 1.427 |
| Loss and damage | .734 | 1.477 |
| Injuries to persons | .874 | 1.229 |
| Clearing wrecks | .147 | .348 |
| Operating marine equipment | .868 | .667 |
| Outside agencies and commissions | 1.975 | 1.300 |
| Rents for tracks, yards, and terminals, etc | 2.388 | 2.023 |
| Other expenses | 2.574 | 1.894 |
| General expense | 4.521 | 3.736 |
| Grand Total | 100.000 | 100.000 |

Operating expenses of steam railroads, given in the accompanying table, are changed by electrical operation about as follows:

COMPARISON OF EXPENSES OF STEAM AND ELECTRICAL OPERATION.

| Motive power. | Steam. | Electric. |
|---|---|---|
| Maintenance of roadway and rails | 11.98% | 10.00% |
| Repairs and renewals of locomotives | 7.66 | 4.00 |
| Engine and roundhouse wages | 9.37 | 6.00 |
| Fuel and power for trains | 11.48 | 6.00 |
| All other items | 59.51 | 56.00 |
| Repairs and renewals of overhead work | | 1.00 |
| Totals | 100.00% | 83.00% |

Repairs, wages, and fuel of many steam railroads are frequently 30 per cent. higher than the average.

The exact amount which can be saved in the above items by the use of electric power depends largely upon the density of traffic, the cost of coal or water power, and the local situation; but, in general, competent engineers hold that many railroads can reduce the percentages noted for steam operation to those noted for electric operation. The conditions are even more favorable for a reduction in operating expenses when a new road is built and operated with electric power.

Comparable conditions of operation must be considered, including all of the freight and passenger service, and a sufficiently long run.

Decrease in operating expenses, with electric traction, is now found to amount in the aggregate to a relatively large sum. The subject was first analyzed by Mr. William Baxter in a technical article in the Electrical Engineer, New York, February 19, 1896. The writer of this book presented the subject in greater detail in a paper before the Northwest Railway Club in January, 1901 (St. Ry. Review, Jan. 15, 1901, p. 39; St. Ry. Journ., March 9 and 30, 1901, p. 328). Messrs. Lewis B. Stillwell and Henry S. Putnam have treated the subject comprehensively in a paper on "The Substitution of the Electric Motor for the Steam Locomotive," to American Institute of Electrical Engineers, January, 1907.

The classification of operating expenses in the Interstate Commerce Commission's annual reports are often used as a basis for comparisons of the cost of steam operation under existing conditions with the probable operating results by electricity. Heretofore the latter were estimates by operating engineers or engineers for electrical manufacturers. Many were biased. However the records of the Long Island, West Jersey & Seashore, New York Central, New Haven, Erie, Grand Trunk, Great Northern, and many other railroads are actual. The records are now being compared with results from steam traction; and some general facts regarding the financial value of electrification are thus being established. Some facts are being furnished to electric traction engineers and to the technical press.

The physical advantages of electric power, when properly applied to railways, have actually decreased the operating expenses and increased the net earnings. The matter therefore deserves study. The best of the meager financial data which are now available will be considered briefly, and *reasons* given for the conclusions reached.

### OPERATING EXPENSES.

**Cost of maintenance of way,** particularly of the roadway and rails, is reduced when electric power is used, for several reasons:

a. Rotary motion and steady continuous effort of balanced armatures of spring-mounted motors cause less track shifting, rail spreading, damage and breakage at switches, at special work and at curves, and less loss to roadbed, masonry, steel bridges, heavy grades, and trestles, than is caused by the steam locomotive, with its long rigid wheel bases, its concentration of weight per axle, the pounding of its unbalanced drivers, the varying reciprocating effort of its pistons, and its enormous thrusts and nosing effects.

b. Weight of electric locomotives is about one-half of the weight of steam locomotives, per h. p. developed. See tables pages 56 and 291.

c. Distribution of the weight of the electric locomotive and of the motor-car train is materially better than that of the steam locomotive hauled train.

"Mersey Railway records for three years of steam traction fairly compared with three years of electric traction, show that the effect of electric traction on the maintenance of the permanent way has been to reduce the cost of maintenance per ton-mile from 0.0416 cent to 0.0240 cent; and as regards the life of rail under the two systems, the average rolling load over the track before the rails require renewing is increased from 32,000,000 to 47,500,000 tons." J. Shaw, before British Institution of Civil Engineers, November, 1909.

Burgdorf and Thun Railway, a steam road, electrified in 1896, has found that the expense for track maintenance has decreased. Tissot.

Metropolitan West Side Elevated Railroad, Chicago, reports:

"The fear that renewal of track, frogs, switches, armatures, commutators, gears, pinions, etc., might after a certain period become expensive has not been realized after 10 years of constant heavy service. At the same time the service has been immensely improved in frequency, speed, and general desirability." Brinckerhoff, to A. I. E. E., Jan. 25, 1907.

Non-spring-borne weights of motors, with low center of gravity, on small driving wheels are harder on the special track work, crossings, and curves than on the main track. Ordinarily, however, the service with electric trains is at least double that of steam; and the cost of maintenance of way and structures, and of rails, increases as the car or ton-mileage increases. The additional hammer of the small wheel when going over the intersecting gap of the crossing, coupled with the non-spring-borne weight of the motors, has been found to decrease the life of the crossing. On the straight track, no definite opinion can be formed that there is an increase or decrease. The difference is not very marked. If acceleration rates with steam locomotives were high, the weight would be increased, making steam locomotives more severe on the track.

In high-speed electric railroad train service, weights of large armatures and motors must be spring-borne.

**Cost of maintenance and repairs of equipment** is decreased with electric power for the following reasons:

1. Simplicity of moving machinery and apparatus is evident.
2. Friction of electric power equipment is smaller.
3. Depreciation rate is therefore much slower.
4. Inspection required to maintain equipment is less.
5. Repairs and renewals of electric locomotives and motor cars are less than with steam locomotives, as is detailed later.
6. Coal and water supply substations, with labor to maintain them, are not needed. These are concentrated for economy at one station.
7. Fewer locomotives are required to do an equal amount of work. Three electric locomotives will ordinarily replace five steam locomotives.
8. Wrecks are fewer, and the expense in connection therewith is less. Wrecks are decreased by automatic electric devices, meters, circuit control, etc., as described under Safety.
9. Cleaning and renovating of car equipment is a smaller item. Steam locomotive smoke, dirt, and cinders, when mixed with condensed steam, cling tenaciously to cars, seats, varnish, and paint; and their removal is expensive, and wears the materials.
10. Painting and cleaning of cars, stations, overhead bridges, and tunnels are less in the absence of locomotive gas and smoke.
11. Corrosion of steel in structure, viaducts, telegraph wires, signal cables, pipes, rails and spikes is also less.

These items, except the last, are considered in detail in other chapters, under Maintenance of Electric Locomotives, and Motor Cars.

**Wage expense is reduced** where electric traction is used.

1. Locomotive and roundhouse work is less. The cost of maintenance of the electric locomotive is about 50 per cent. of that of the steam locomotive. The inspection and repairs are less; time is not required for drawing fires, washing flues, cleaning boilers, etc.
2. Locomotive enginemen do not receive the same high rate of wages on electric locomotives as on steam locomotives. Electric locomotive operation is simpler and requires less skill than the running of a complicated power house on wheels. On many electrified roads the same wages are paid now as before, but this may not be continued. The New York Central zone rates are 38.5 cents for enginemen on electric and steam trains, 23 cents for firemen on steam trains and 21 cents for helpers on electric trains.
3. Helpers are generally superfluous with electric locomotives, altho one helper is always necessary on heavy trunk-line, high-speed service. There is some work, in terminal yards, on work trains, construction work, branch lines, etc., where one locomotive man is ample. On some German

and Italian railways the train conductor rides with the electric locomotive operator; and is competent to take his place in an emergency.

Motor-car passenger trains require only three men per 6- to 10-car train, a motorman, conductor, and brakeman; and the total wages paid are about one-half of what was formerly paid for the same service with locomotive-hauled trains.

New York Central motor-car trains run at high schedule speed in the electric zone from the Grand Central Station to North White Plains, 24 miles, and to Hastings, 20 miles; and with a car mileage of 4,000,000 per year, a large saving is made. Similar results are obtained on other electrified steam roads.

4. Automatic devices, like the dead-man's handle, and interlocking devices on control mechanism, make two men in the cab unnecessary in many cases. Meters in the cab facilitate intelligent operation.

5. Ton-mileage per day with electric traction for freight trains is also greater. A saving of 25 per cent. is to be expected in wages, because of the higher schedule speed of freight trains, particularly so on heavy grades. Electric passenger locomotives make double the mileage of steam passenger locomotiveson the same line, because there are fewer and quicker switching movements and less time is spent in repair and inspection, in building fires, in washing out, etc.

6. Increased hauling capacity with electric traction makes a remarkable saving in the wages of the engineman and the fireman, and also in the wages of the entire train crew, because, with the longer train at somewhat higher speed, the wages paid *per ton-mile* hauled, or *per train-mile* run, are less.

7. Double-heading of electric locomotives does not require a duplication of the locomotive crew, because the control is so arranged that one engineman operates both units.

8. Time is not wasted, with electric power, in delays caused by lack of good coal, inefficient steaming, bad water, and cold weather; and less time is needed for road repairs.

9. Electric locomotives can perform more continuous service, and wages expended in shopping are saved.

10. Less time and labor are required for switching service.

11. Labor is more efficient, because a better class of skilled men and laborers are attracted by electrical operation. Cleanliness and skilled mechanical work are contrasted with washing of hot boilers, removal of boiler mud and scale, dirt and smoke, and ash and clinker cleaning.

The wages paid at the central electric power station and on transmission line repairs are in themselves a large item; but they are a small item per train-mile, or per ton-mile hauled.

12. Speed of suburban trains is increased, 25 to 50 per cent. It is

clear that higher speed saves in wages. In service with frequent stops, the rapid acceleration of trains radically increases the schedule speed. In fact, electric railway operators join in stating that steam locomotives could not handle the now largely augmented traffic and the present schedules, without prohibitive expenditures for terminal trackage, locomotives, cars, trains, and wages.

**Fuel and motive power expenses** per ton-mile or per train-mile hauled are reduced about 50 per cent. with electric traction, because:

1. Cheap water power reduces the cost of fuel, and for that reason water power has been adopted by a large number of electric railways. The subject is detailed under Steam, Gas, and Water Power Plants.

2. Cheap fuels reduce expenses. The cheapest fuels are burned on suitable stokers of large boilers with ample draft in modern power plants The lowest grades of fuel, lignites, culm, cheap screenings, and waste products can be burned under properly designed boilers and in gas producers. It is predicted that many important railway power plants will be built at coal mines to use the abundant low-grade fuel which is now wasted and that the power will be transmitted by wires, rather than by high-grade bituminous or anthracite coal, or fuel oil for service near terminals, tunnels, resident districts, flour mills and factories where cleanliness is necessary; and at forests, wharves, sheds, and yards where the fire risk must be reduced.

3. Power is produced efficiently on a large scale, by means of economical apparatus, in one plant, and not in many relatively wasteful small locomotive plants.

"Railroads will have to come to electricity, not only to get a larger unit of motive power, but on account of *fuel.* We have to use fuel to carry our fuel and there are certain limitations here, particularly when we consider the distribution of the coal-producing regions with respect to the major avenues of traffic. This great saving, resulting from the use of electricity is apparent, quite aside from the increased tractive power and the train load." E. H. Harriman, Elec. World, March, 1907, p. 538.

4. Furnace efficiency of boilers is high because: Furnaces and grates are properly designed to burn the bituminous coal available; coal is fed and ash is removed continually, not intermittently; sufficient and proper draft is provided; firemen are skilled; combustion space is ample; fire-brick arches further combustion before the gases reach the boiler surfaces; load is uniform or does not change quickly; nor is it necessary to have great overloads at a central station. The opportunity to burn common bituminous coal efficiently, in an individual locomotive furnace, does not exist. A central station furnace which smokes is seldom found, and

indicates gross negligence, lack of common engineering skill in design, or lack of money to build properly.

5. Utilization of the power produced is efficient because there is a reduction in the amount of power required.

a. Weight of the electric locomotive is only one-half of the weight of the steam locomotive and tender, as was explained. The excess weight of a common 170-ton steam passenger locomotive, over a 100-ton electric locomotive, with equal weight on drivers and with equal capacity, is large. Many electric locomotives weigh less than a loaded coal and water tender. If hauled 100 miles per day, 300 days per year, at a net cost of $0.003 per ton-mile, the saving of 70 tons, made possible with electric power, is $6300 per year per locomotive. An additional saving of 15 to 45 per cent, in weight, is made by the motor-car train.

b. Power is transmitted to the axles with minimum friction, by means of economical motor drive, and not by cumbersome mechanism. Head-end, bearing, and rubbing friction are less.

6. Regeneration of energy on the down grade and in braking, which is practical, represents a large possible saving.

Fuel saving is discussed qualitatively under "Electric Locomotives."

## INVESTMENTS INCREASED OR DECREASED.

**Investments are generally increased** with electric traction. This is clearly a set-off. Net earnings are reduced by the added interest, the depreciation, and the taxes on the investment in the power plant, transmission lines, and motor equipment.

Capitalization per mile of track is not an indication of high or low net earnings. The important point in operation is to *utilize* the investment in the road to the highest degree and to reduce the capital charges by providing the maximum tonnage per mile of track. Ample capacity and economical power with electric traction favor this plan of operation.

Higher investment in electric motive power equipment is a drawback, but the cost of electric motive power is only a fraction, about 20 per cent., of the total cost of a railway, as is detailed in Chapter XIV.

**Investments are decreased** in many cases:

a. Immense investments are unnecessary when, with reasonable investments in electric motive power, existing facilities and expensive terminals suffice for decidedly greater traffic.

b. Terminals and entrances to our larger cities, for both freight and passenger tracks, may be made underground, or by superimposing the tracks, either above or below the ground level.

c. Grades may be steeper, and total investments be decreased, because the height and length of bridges may be less, and roads may be

shorter. The Colorado Springs and Cripple Creek Railway is 19 miles long, with 5 per cent. ruling grade and 3 per cent. average grade; while the steam railroad, with low grades between the same terminal points, 17 miles apart by air line, is 52 miles long. E. T. W., Sept. 25, 1909.

d. Limiting grades are higher on electric railroads. The steeper grade may result in a shorter route, or in reduction in the amount of the cuts and fills. The traffic is not throttled or congested at the mountain division. The "ruling grade" becomes an obsolete term and, in place thereof, the longer trains are limited by the "ruling curve."

e. Roadbed may cost less. Narrow-gage railways, which are common in Europe, use electric power where steam locomotives would not have the requisite capacity for heavy and long trains.

f. Substructures may be lighter with electric power, because of the weight distribution and the absence of reciprocating machinery.

g. Motive power equipment and rolling stock are used efficiently. More work is accomplished over a given track, or tunnel section, or over a mountain division. Time is saved by higher speed and by efficient and simple movements, to prevent further investments for double tracks, bridges, tunnels, and rolling equipment. The cost or amount of rolling stock needed is frequently reduced 20 per cent. by advantageous use.

h. Three electric locomotives replace five steam locomotives, because the former can be kept almost continuously in operation.

i. Round-house equipment is reduced, by the substitution of inspection sheds for round houses, turn-tables, heating plants to wash out boilers, coaling plants, pumps, water tanks, and piping.

j. Heavier traffic on 2.2 per cent. grades is practicable with electric power; and this prevents immense investments for double tracking or for grade reduction. As an example of the latter:

Bernese-Alps Railway, Switzerland, has recently bored a new double-track tunnel, the Loetschberg, thru the Alps, for a direct north and south line between London and Milan, via Berne and the Simplon Tunnel. Two distinct plans for handling the traffic were under consideration —a 1.5 per cent. grade route with a tunnel 13.1 miles long, and a 2.7 per cent. grade route with a tunnel 8.5 miles long. Steam locomotives would have required the low-grade route. Electric locomotives are used and they saved about $6,000,000 in the cost of the tunnel.

## EARNING POWER AND NET EARNINGS.

The ratio of *gross earnings less operating expenses* to *investment* is a measure of the earning power of railways. It is therefore essential that gross earnings be larger, or that operating expenses be smaller, in order that net earnings shall be in proportion to the total capital invested.

Analysis is simpler when the *increased net earnings* are compared with the *increased capital* required to furnish the electrified track or other improvements.

Gross earnings are easily compared; but a comparison of operating expenses, before and after electrification, is difficult. It is practically impossible to compare directly the cost of steam and electricity per train-mile. The introduction of electricity generally alters the type and size of the train. Each steam locomotive-hauled train with five to ten passenger cars is changed to several 3- or 4-car trains, operating on the multiple-unit system. In freight service the trains may be either decidedly longer, or have a higher schedule speed.

Comparison should be made on the basis of good service, on the basis of traffic hauled, per seat-mile, per car-mile, per ton-mile, but not per train-mile. In some cases it is found that the cost of service by electricity is higher than for service by steam, because of the faster rate of acceleration, higher speed, better care of equipment, and the better service provided; but all of these may radically increase the gross earnings. It is recognized that there is an increase of traffic, and a changed condition of business, when electric power is used on a large scale or main lines.

INCOME ACCOUNT OF STEAM RAILROADS OF THE UNITED STATES.

| Item. | Total, 1908. | Per track-mile. | 1908. | 1907. |
|---|---|---|---|---|
| Gross earnings.................. | $2,458,000,000 | $7,366 | 100% | 100% |
| Operating expenses.............. | 1,670,000,000 | 5,005 | 68 | 66 |
| Income from operation.......... | 788,000,000 | 2,361 | 32 | 34 |
| Interest on debts, paid.......... | 459,000,000 | 1,377 | 19 | 16 |
| Dividends paid.................. | 228,000,000 | 682 | 9 | 9 |
| Available for improvements..... | 101,000,000 | 302 | 4 | 9 |

Cost of road and equipment was $19,472,650,000 for 333,646 miles of single track or $58,363 per mile. The year 1908 represents a lean year while 1907 was more prosperous.

EXAMPLES OF FINANCIAL ADVANTAGES OF ELECTRIC TRACTION.

Data per mile of track on a prairie division:

| | | | | |
|---|---|---|---|---|
| Motive power.................... | Steam | | Electric | |
| Investment...................... | $30,000. | | $36,000. | |
| Gross earnings.................. | | $5000. | | $6000. |
| Operating expenses.............. | | 2800. (56%) | | 3000. (50%) |
| Net earnings.................... | | 2200. | | 3000. |
| Interest on investment.......... | at 6% | 1800. | at 7% | 2520. |
| Net income...................... | | 400. | | 480. |

Estimate for a proposed 200-mile road:

| *Assets:* January 1st. | 1910 | | 1912 | |
|---|---|---|---|---|
| Cost of road and equipment | $8,000,000 | | 10,000,000 | |
| Materials and cash on hand | 400,000 | | 430,000 | |
| Total cost of road | 8,400,000 | | 10,430,000 | |
| *Liabilities:* | | | | |
| Capital stock | 4,000,000 | | 4,000,000 | |
| Funded debt | 4,000,000 | | 6,000,000 | |
| Surplus | 400,000 | | 430,000 | |
| Total | 8,400,000 | | 10,430,000 | |
| Year ending Dec. 31. | 1910 | | 1912 | |
| Motive power | Steam. | | Electric. | |
| Gross earnings from operation | 1,000,000 | | 1,250,000 | |
| Less operating expenses and depreciation | 650,000 | (65%) | 750,000 | (60%) |
| Income from operation | 350,000 | | 500,000 | |
| Deductions from income: | | | | |
| Interest on funded debt, 5% | 200,000 | | 300,000 | |
| Net income or net earnings | 150,000 | | 200,000 | |
| Dividends on stock, 3% | 120,000 | | 120,000 | |
| Surplus from operation | 30,000 | | 80,000 | |

Electric traction increases the cost of road and equipment, and thus the interest charges on funded debt are greater. Gross earnings increase, and expenses decrease.

Manhattan Elevated Railroad Company statistics are presented:

| Comparison: | Steam, 1896. | Electric, 1904. |
|---|---|---|
| Operating expenses, per cent | 58.1 | 41.2 |
| Passengers carried | 185,138,000. | 286,634,000. |
| Car mileage | 43,241,000. | 61,743,000. |
| Receipts per car-mile | 21.60¢ | 22.95¢ |
| Operating expense per car-mile | 12.20 | 9.50 |
| Operating expense per passenger | 2.92 | 2.04 |

| Operating expenses per car-mile: | Steam 1901 | Electric 1904 |
|---|---|---|
| Maintenance of way and structures | 0.927¢ | 1.047¢ |
| Maintenance of equipment and plant | 1.304 | 1.325 |
| Power supply, for transportation | 10.046 | 7.096 |
| Total operating expense per car-mile | 12.277 | 9.468 |

London, Brighton & South Coast Railway, electrified in 1909, reports that there has been, as compared with the corresponding period of the last year of steam operation, an increase of 55 per cent. in the number of passengers carried, and a recovery of practically the whole traffic abstracted by the local electric tramways.

West Jersey & Seashore Railroad, running between Philadelphia and Atlantic City, increased in traffic at a rate of less than 2 per cent. per year until it was electrified in 1907. The first year showed an increase in gross earnings of 20 per cent. over the preceding year of steam operation; and operating expenses were decreased. See Chapter XV.

New York Central Railroad terminal division at New York, where economy could hardly be expected because of the short distance and the time electric power had been used, to Sept., 1907, shows a decided decrease in operating expenses after allowing for the increased capital charges for electrification; the prediction is made of still larger savings. Wilgus, A. S. C. E., March, 1908.

Long Island Railroad was the first steam railroad company to use electric power on a large scale over a considerable portion of its line. Operation began in 1905. The 1909 mileage was 120; the number of motor cars, used in 3- to 6-car trains, was 136. The annual report of President Peters for the year ending December 31, 1908, endorsed the electric railway service, which had been in operation for about four years. In addressing the stockholders he stated:

"The extension of electric service from Queens to Hempstead was put in service May 26, 1908, and all train service to Hempstead branch has since been operated by electric power. The results therefrom are very satisfactory both in increased business and in economy. The general results on that portion of your system which has been electrified fully justified the expenditure made in accomplishing that result."

Long Island Railroad has recently announced that, as a result of the electrification, the road was operating at a cost sufficiently below that of steam operation to pay the interest on the extra investment and to yield a handsome surplus. The steam road had been operating with an annual deficit. The results were a pleasant surprise, in view of the incompleteness of the installation and the large expenditures at terminals, power stations, etc., from which only a small advantage could be at once derived.

## BY-PRODUCTS OF ELECTRIFICATION.

**By-products, or incidental advantages,** often accompany electric traction. For example, several by-products of the New York Central electrification were the following:

Underground or sub-tracks were used for all suburban railway trains, the level being retained for main-line trains. This saved, at the terminal station, two city blocks, valued at $50,000,000.

There was a saving of $200,000 per year in current for lighting terminal yards, power for isolated service, and for freight elevators.

There was a saving of $114,000 per year on switching, now carried on during the period of non-peak loads at the power station.

Safety devices in connection with signals allowed a greater degree of automatic control of train movement. The second engineman was superfluous, even for checking signals. A great saving in labor resulted.

Railway plant service by electric power combined effectually with electric lighting, air compressing, water pumping, exhaust steam heating, and power service, to reduce materially the fuel, labor, and maintenance cost of these services.

Double decking of freight tracks in buildings and freight storage warehouses will economize in real estate, and in freight handling.

Streets again occupy the space over many depressed tracks leading from the railroad terminal. Frequently these cross streets are several blocks long, and give to the public very valuable and increased facilities for normal street traffic.

Buildings were placed over the tracks to use the valuable real estate for immense office buildings, substations, a Government Post Office, etc.

Hudson & Manhattan terminal building, which is one of the most important office buildings in New York City, is located over subterranean railway loops.

Real estate salvage following electrification generally amounts to large sums, since the abolition of the steam locomotive enables sweeping changes to be affected along the route, and in the terminals and yards, allowing the construction of new streets, and the building of commercial structures, union stations, post office substations, etc., immediately above the electrified trackage. Real estate and property along the right-of-way generally show a great increase in value for residential and office purposes, resulting from cleanliness and the absence of noise from exhaust steam.

## ADVANTAGES DURING BUSINESS DEPRESSIONS.

Advantages during business depressions, such as the financial flurry which began in October, 1907, and ended about May, 1909, are noted.

The Commercial and Financial Chronicle of March, 1908, gives the January, 1908, losses by steam railroads, compared with those of January, 1907; and the Electric Railway Journal of April 4, 1908, quotes the gains of electric railways for the same period.

COMPARISON OF EARNINGS.

| Railways. | 103 representative steam roads. | 29 representative electric roads. |
|---|---|---|
| Gross earnings.............. | 12.9% loss. | 5.3% gain. |
| Net earnings............... | 22.9% loss. | 10.0% gain. |

Statistics recently compiled show that electric railways fared much better than steam railroads during the late depression.

Returns from 203 electric railways show an *increase* in both gross and net earnings in 1908 over 1907. The gross earnings for 1908 were reported as $280,262,681 against $278,387,557 in 1907, and net earnings, $117,441,782 as against $114,406,399 in 1907.

The gross earnings of 164 steam railroads in 1908 decreased 11.89 per cent. compared with 1907, while electric railways increased their gross and net earnings. If the record had been on heavy electric railways in place of strictly passenger lines they would have been more comparable. Voegelin, in Railroad Age Gazette, Dec. 24, 1909.

## ADVANTAGES IN COMPETITION.

Advantages in competition are obvious at this time. Lower fares and freight rates will be the rule with electric trains because the cost of operation with electric power is lower; because the method of operation is improved; and because, cumulatively, the density of increased traffic makes for economy. The product of the lower fare by the number of passengers, and the product of the lower freight tariff by the tonnage are both greater than the corresponding income from less business at higher rates, when the railway uses a motive power having the greatest physical advantages and economy of operation.

Mersey Railway, of England, Manhattan Elevated Railroad, and scores of steam railroads have been compelled to adopt electric power to avoid bankruptcy.

Boston & Albany, Boston & Maine, and the New Haven road have recently been subject to such competition by the growth of suburban electric railways at Boston that, to regain their traffic from their terminals and to handle business with economy, they are now considering the electrification of large zones radiating from the North and South stations at Boston.

A very large traffic, which was previously taken away from the Lancashire & Yorkshire Railway by electric lines which ran parallel to it, was regained, after the road was electrified, according to J. A. F. Aspinwall, General Manager and Engineer.

The subject of competition and patronage was reviewed on pages 20, 21, 22.

## SOCIAL ADVANTAGES.

One advantage of electric traction, which the broad-gage engineer should not fail to see, is that by its use human society is distinctly benefited. Engineers are employed primarily to save money for stockholders. There is, however, real and legitimate gratification when the engineer realizes that, with the reduction of the cost of freight and passenger transportation by the use of better and more economical motive power, he has effected safety, health, and comfort in travel, a conservation of natural resources, and improved social conditions. Professional success of the engineer may well include fame and honor and the accumulation of wealth, all of which are worthy ends; but if engineering is a worthy art, it must also include the promotion of welfare and happiness of others, and a bettered condition of humanity.

There is no work which gives such gratification in transportation service as the making of provision for greater safety to property, and particularly to life. Safer travel, fewer wrecks, and a saving in time furnish to all society pleasures, contentment, and freedom from anxiety. The engineer often has an opportunity to prevent social unhappiness incidental to economic waste. There is an incentive in such work.

**Conservation of natural resources** results from efficient use of coal. Much of the coal mined is now used very wastefully in locomotive furnaces. The coal used at the central electric railway power station is burned economically, by mechanical stokers, and the records show that 50 per cent. of the cost of fuel is saved, per ton-mile, in transportation. Coal is expensive; it is generally hauled 500 to 1000 miles before it is used, and it should be burned in an economical manner.

Labor is decreased, as a result of the efforts of the engineer to save coal, which now requires so much brutal labor and drudgery.

The governments of Sweden, Switzerland, Germany, and Italy use water powers and lignite coal fields in order to prevent the necessity of importing foreign coal. This plan, in connection with the electrification of their railways, will conserve the natural resources, and, moreover, will keep the nation's money in the country. Many railways in America will consider the installation of electric power stations at coal mines to utilize the waste coal, culm, duff, dust, lignite, and screenings.

**Reduction in the cost of freight transportation** will follow the reduction already made in the cost of fares. Electric power, with its physical advantages, reduces the cost of transportation by reason of the economies effected. More scientific and efficient methods can be used in operation. Lower freight rates allow the movement of low-grade freight, and improve the "business situation" on which most of the people of the country are more or less dependent.

**Cost of living is decreased** when electric lines make suburban and country districts accessible, by frequent service, fast schedule, and low fares. Lower rent, good health, and reduced prices for vegetables, fruit, and transported food will prevail. (It is, however, not the trolley car which will carry the suburban resident, but the high-speed electric train on the private right-of-way with a terminal station in the heart of the business district. Distances are really measured on a time basis, and the time of regular daily travel should not exceed one hour.)

**Esthetic enjoyments** are realized when electric traction is used. Cleanliness and fresh air contribute to the pleasures of travel, and consequently to the welfare of the public. Ventilation of steam trains is bad, for it is necessary to exclude the locomotive gas, smoke, and cinders. It is not practical to ventilate even sleeping and dining cars in a suitable manner. The majority of travelers do not ride in the sleeper, but in the crowded coaches and their health must be conserved. The Lackawanna Railroad uses anthracite coal, and therefore advertises cleanliness via the "white way." Travelers remember the cleanliness of electric roads, from Philadelphia to Atlantic City, from New York to Stamford, to White Plains, and to Yonkers, the tunnel connections from New York City to distant points on Long Island and New Jersey, Rochester to Syracuse, Chicago to Aurora, Chicago to Milwaukee, Springfield to St. Louis, etc.

**Smoke from locomotives** is a nuisance not to be tolerated in business and resident districts. The injury to persons, to their health, and to their property is large. Smoke is a hindrance to the development of civic beauty and refinement. The sociological importance of cleanliness is well understood. The financial importance of the subject is becoming known. The cost of cleaning smoke and dirt from the body and the grime and soot from the clothing is large. The traveling public includes those who journey for pleasure and necessity, but all want fresh air and cleanliness. Black smoke from the stacks of locomotives is especially a nuisance. The use of fuel oil, coke, smokeless and anthracite coal, is expensive, and not a practical remedy. It is possible to operate locomotives without smoke, but it is not economical to do so, on account of the labor involved, and the additional maintenance cost at the furnace.

Lives of millions of people are shortened by the necessity of breathing gases and soot arising from the use of steam locomotives in cities.

**Noise** from exhaust of steam locomotives disturbs sleep, particularly that of nervous or sick people, young or old. Portions of cities, even at some distance from steam railroad tracks, are now rendered by this noise absolutely undesirable for homes. The noise from train movement is not objectionable, but that from the harsh, unmuffled exhaust is detrimental to public welfare.

Property close to steam roads suffers from cinders, smoke, noise, and dingy conditions, caused by the steam locomotives; it is not desirable for offices or residential purposes. Windows cannot be kept open, and not only cleanliness, but also good health is affected adversely. When roads are electrified, property increases very much in value, and apartments which were uninhabitable can be occupied without disturbance. Real estate dealers recognize this fact.

Ordinances now prohibit the use of steam locomotives within large parts of Annapolis, Brooklyn, Hoboken, and New York City. Similar ordinances will soon govern in Boston, Washington, Buffalo, Cleveland, and Chicago.

**Social conditions** are improved, as a result of low passenger rates and decreased cost of living. These two items affect largely the comfort, welfare, and amount of recreation of the inhabitants of cities. In some American and in many foreign cities, millions are saved every year, in hospital bills alone, to say nothing of happiness, health, and improvement in social conditions, where the inhabitants of the congested districts get to the country, to the suburbs, and to the lakes cheaply and frequently.

With the more frequent and cleanly service which can be furnished with economy in electric traction for railway trains, population will be attracted to the suburban territory many miles from the city, as it is not under the present conditions.

### OBJECTIONS AND OBSTACLES TO ELECTRIC TRACTION.

There are objections and obstacles which prevent a general application of electric power to railways. Reasons for these are here outlined.

**Conservatism** is generally a marked characteristic of railway men, to whom, naturally, the untried electric railway is not attractive. Capital also is shy and hard to interest in a new investment. Electric railways have usually been built by successful promoters, men with daring, enthusiasm, and resourcefulness, men who have waited and worked for years to carry out their plans.

**Crude presentations** of situations, made by enthusiasts, young engineers, New York-Chicago air-line promoters, and men without experience in railroading, have been responsible for much opposition and distrust. Electrification plans must be well presented.

Lack of ample information on the part of the promoter, of his engineers, and of conservative capitalists, frequently results in the abandonment of deserving propositions. There may be simply a lack of facts on operation, and experience and resources with which to surmount obstacles. There are, however, conditions which make electrification impractical, as detailed in Chapter XIV, "Procedure in Railroad Electrification."

**Investments are always larger** with electric traction than with steam traction, and there is an added annual charge for interest, taxes, and depreciation. The extra investment may be justified by increased net earnings, but the initial outlay required is often a handicap.

Some American railroads have already issued stocks and bonds up to the limit of their average earning capacity. Other roads can raise the funds, but the terms would bring an undesirable burden, too heavy to be carried comfortably. Money for improvements of undoubted value is frequently unobtainable when large amounts are needed. Increased economy, with electricity, may be in sight, but it is quite another thing to take advantage of electric traction.

Many vested interests are deeply concerned in the railroad, as one finds when the electrification of a road is considered. The business interests of the country and of the railroad are not separated, but are dependent on each other, and sometimes these interests are opposed to a change in motive power.

The actual cost of the electric power equipment required is, however, generally a small portion of the total cost of a railroad. This is not always understood by those who oppose investment for electric traction.

In many cases electrification was or will be compulsory, and estimates and reports made by railroads have been and certainly will be adverse, in fact a railroad is not expected to minimize its difficulties when a large possible expenditure confronts it.

**Complication** is suggested by the central electric power station, electric generators, transmission lines, distribution at high voltages, transformation and utilization of power by motors, in place of a multitude of simple steam locomotives. The necessity exists for different tools, and trained labor for the inspections, maintenance, and repairs of the electrical equipment. Added standards, patterns, castings, and also office records are needed if the two motive powers are combined on a steam and electric railway. Technical skill of a different grade is required with electric traction.

**Systems of electrification are confusing,** for there are advocates of the third-rail vs. trolley, direct current at 1200 volts with many substations vs. alternating current at 6000 or 11,000 volts; 25 vs. 15 cycles; single-phase vs. three-phase current; series-compensated vs. series-repulsion motors. Some electric systems are not interchangeable. Moreover, each system has been so successfully applied to train service that the best is not easily selected. Steam railroad engineers, after 50 years of splendid experience, are still unsettled on the relative merits of different mechanical types and frames; singe vs. compound engines; 2- vs. 4-cylinder compound; balanced engines vs. track pounders; and there are to-day may distinct kinds of locomotives advocated for common railroad service.

**Danger** to employees and to the public, from the use of electric power, is to be considered. Accidents occur from unprotected third rails and from crude overhead high-potential construction.

New York, New Haven & Hartford Railroad has over 100 miles of 11,000-volt trolley in regular freight and passenger service on its New York Division. There have been accidents and fatalities, and a few trainmen have been killed by contact with the trolley wires; but no trainmen has ever been killed in the locomotive or motor cars.

Prussian State Railway has made tests on its high-voltage railway lines to determine the liability of fire and the danger to life resulting from cars coming in contact with broken trolley wires. Passenger cars with standard wooden bodies were forced in contact with live wires. Tests showed that every contact between the car and the wire produced a short circuit which instantly tripped the circuit breaker in the substation and automatically cut off the power. In a few cases imperfect short circuits were established, and fire resulted; but if there was the slightest movement of the car there was a complete short circuit and the power was cut off. Tests made inside the car showed that in no case was any leakage produced which could be detected by the human hand or body. In practice, grounding wire are provided on car roofs to make sure that there will be sufficient current to open the automatic circuit breaker and thus prevent risk to trainmen and passengers.

Electric motive power at practical voltages will always be dangerous; high pressures on steam locomotives are always dangerous; but all are necessary for economy.

**Dependence on electric power plants** for the entire motive power of important railways may seem unwise. The break-down of a steam locomotive cripples only a short section of the division. A failure of electric power means that the expense continues as usual, but with a loss of earnings, a loss of reputation, and demoralization of the men, management, and traffic. The capacity of a division of a railway which uses electric power is decreased by an accident to the transformers, controllers, transmission, or contact line; and, in some measure, trains will be bunched.

There is, however, in common power plants, because economy and physical reasons require it, a duplication of boilers, turbo-generators, transformers, and feeders. The important exception is the overhead contact line, and it is essential that simplicity should govern here because on single-track roads this is the only equipment which cannot be easily duplicated. Reliability of service in practice has not been questioned. Prudence dictates that two separate power plants be erected for important long trunk-line railroads.

**Transmission losses,** with large amounts of power, were so large, until about 1896, that power transmission for railroad service was not practical. Power could not be furnished directly from one central power plant to 15 scattered electric locomotives until the power could

be transmitted economically at least 30 miles. Electric traction for trunk-line service required that high voltages—above 5000 volts—be utilized on the contact line. High-voltage transmission and contact lines have been so perfected that reliable electric power is now delivered, with very small loss, to distant railroad trains.

**Interference with signal systems,** blocks, and telephone and telegraph lines is no longer caused by electric currents. Apparatus has been devised to effectually prevent interference from high-voltage lines, by leakage, induction, static discharges, or ground currents. Reference: Taylor, to A. I. E. E., Oct., 1909; G. E. Review, Aug., 1907.

**Discard of steam locomotives** is not necessary when electric traction is adopted. Steam locomotives are short-lived at best, and 12 years is a long life if the equipment is really used. Steam locomotives may be used advantageously on other divisions. Renewals of locomotives by purchases of equipment are charged to maintenance, not to construction.

**Illinois Central Railroad** case is here considered briefly. Upon demand of the Chicago City Council in 1909 that all suburban lines be changed to electric power, it gave four reasons why electrification could not be undertaken.

First.—The state of the art is such that electric operation of large freight terminals at Chicago is impracticable.

Second.—Operation by electricity would not result in economies sufficient to pay an adequate return on the large additional investment.

Third.—Interchangeable electric motive power equipment for motor cars and locomotives has not yet been developed.

Fourth.—Smoke nuisance can be avoided by using coke as fuel for locomotives and gasolene as fuel for motor cars, and this improvement would suffice in place of electric operation.

Extensive freight terminals are now electrically operated by the Lancashire & Yorkshire Railway, England; by Grand Trunk Railway at its Sarnia Tunnel; by Michigan Central, at Detroit; by Hoboken Shore Railroad, and a score of small terminals listed in Chapter I, which use electric locomotives for freight haulage. The matter of size or degree does not radically increase the difficulty of the situation, but sometimes improves the financial prospect.

Data on cost of operation presented by the railroad were based on 82.9 per cent. operating expenses for steam and 66 per cent. for electricity. Increase in traffic and in gross and net revenue which were not admitted in the Illinois Central report, can be anticipated to a very large extent.

The cost of electrification of 52 miles of suburban road was estimated at $154,000 per single-track mile, a sum which was certainly based on

improvements much more far-reaching than were actually required for providing electric motive power and equipment. Rearrangement of tracks and terminals was certainly advisable, but there was no reason why the substitution of electric power for steam power should necessitate track changes, particularly so when overhead conductors are used.

The financial results from operation on the New York Central and Long Island Railroads are held to have increased the net earnings more than sufficient to pay the interest on the added investment for electrification; and if this is true with passenger traffic from a terminal, additional economies will be effected when the whole road is electrified and the freight and yard work is added.

The third objection reported by the Illinois Central Railroad officials was that at New York City the New York Central and New Haven equipments were not interchangeable, and that the Central could not send its direct-current electric trains over the long-distance 11,000-volt electric lines of the New Haven road. This objection is true. New Haven single-phase, electric motor-car trains and freight and passenger locomotives can, however, run anywhere over the New York Central, Long Island, and Pennsylvania Railroad electric tracks.

Finally, the use of coke and of gasolene for heavy work is an experiment; and, up to this time, there is little to indicate that either fuel would be physically successful. Gas from the coke, and the noise and odor from the gasolene, would be a nuisance; economy would probably not result; and traffic would not be increased with such a motive power.

An important meeting of railroad officials with the transportation committee of the Chicago City Council was held December 8, 1909, at which the electrification of the terminal lines was considered. The railroad men contended that "electrification was impracticable: first, because of *cost;* second, because of *danger* to employees; third, because the science of electrification is *not* sufficiently matured to make it *applicable to the freight terminals.*"

The Illinois Central could adopt electric power to realize higher economy and greater net earnings; but that would precipitate a situation on all the steam roads. The example at the New York City terminals already worries the railroads entering Chicago.

In February, 1911, all of the steam railroads having terminals at Chicago agreed to a 2-year study of the electrification problem, by a Commission of 17 steam railroads executives, city officials and business men, under the auspices of the Chicago Association of Commerce. The scope of the work embraces the following investigations: The necessity for electrification; the mechanical feasibility considering all engineering possibilities and problems; and the financial feasibility, whether the cost is prohibitive and the results commensurate with the cost.

**Electric railroads are often called an experiment for heavy freight and passenger service.** The following railroads are exceptions:

New York, New Haven & Hartford, in trunk-line service.

New York Central, in heavy switching and terminal work.

Hudson & Manhattan Railroad, in tunnel and suburban service.

New York Subway for 10-car trains, in real rapid transit.

Pennsylvania Railroad, in heaviest terminal service.

Long Island Railroad, for dense main-line traffic.

West Jersey & Seashore Railroad, for heaviest passenger service between Camden and Atlantic City, on a double-track, 65-mile road.

Baltimore & Ohio, in heaviest freight traffic thru a tunnel.

Baltimore & Annapolis Short Line, for common railroad service.

All elevated roads, including the Manhattan Elevated, formerly one of the largest steam roads in the country.

Albany Southern Railroad, for freight and passenger work.

West Shore Railroad, between Utica and Syracuse.

Erie Railroad, on its Rochester-Mt. Morris Division.

Michigan Central Railroad, for all Detroit River tunnel trains.

Grand Trunk Railway, for traffic thru the Sarnia Tunnel and grades.

The thru interurban roads of Ohio, Indiana, and New York.

Chicago, Lake Shore & South Bend Railway, for excellent traffic.

Aurora, Elgin & Chicago Railroad, for high-speed rapid transit.

Chicago, & Milwaukee Electric Railroad, for 2-car train service.

Illinois Traction Company, for general freight work and for sleeping car service between St. Louis and Peoria, 172 miles.

Colorado & Southern, for heavy work on grades near Denver.

Spokane & Inland Empire Railroad, freight and passenger service.

Great Northern Railway, for a tunnel on a heavy grade.

Puget Sound Electric Railway, for 3-car passenger train service.

Southern Pacific Company, for suburban traffic near San Francisco.

Huntington roads in California, for heavy trains.

Lancashire & Yorkshire Railway, between Liverpool, Southport, and Crossens, 82 miles of single track, for a large amount of ordinary suburban and terminal service, much like that of the Illinois Central Railroad.

North-Eastern Railway, of England, 82 miles of track for excellent service with electric trains, in both freight and passenger traffic.

Central London Railway, which carries 60,000,000 passengers per year and operates 3-car trains on less than a 3-minute headway.

London, Brighton & South Coast Railway, on 62 miles of 2- to 7-track road, in heavy suburban service.

Paris Subway, which has heavier service than the New York Interborough.

Paris-Orleans Railway, between the Quai d'Orsay and Orleans

station, where all main-line and overland trains are hauled by electric locomotives.

Bernese-Alps Railroad, with heavy thru freight and passenger trains.

Valtellina Railway, of Italy, for light freight and passenger service.

Giovi Railway of Italy, for heaviest freight service with twenty-five 2000-h. p. locomotives, on heavy mountain grades.

**A luxury which the people must pay for** is an objection given at Boston; but electric transportation history shows that when the capital has been wisely invested for improved motive power on electric roads the people are willing to pay for it; and they have usually furnished such an increase in passenger and freight traffic, and in gross and net earnings, that the improvements were not paid for by any increase in rates.

**The financial problem** is reduced to this: Will electric traction for heavy railway service be capable of earning a greater percentage of interest on the invested capital?

In general, it is practical for electric traction to supersede steam traction only where scientific reasons and technical judgment make it clear that the *physical advantages*, capacity, flexibility, simplicity, and safety will produce a definite *commercial advantage.*

Electric traction may be used to prevent or to meet competition, to promote traffic, or to improve the welfare or civic conditions of a city. In special cases, efficient and economical operation may not be paramount, yet even here there must be some financial necessity.

In the business world electric traction is not a matter of sentiment, policy, safety, or cleanliness except when these produce, for the whole railway, greater financial returns.

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## CHAPTER IV.

# ELECTRIC SYSTEMS AVAILABLE FOR TRACTION.

### Outline.

**Classification.**

**Direct-current Systems:**

Generation as three-phase current, transmission at high voltage, transformation to low voltage, conversion to direct-current, substation with attendants along route, 600 and 1200 volts, one overhead trolley, third-rail contact line, two-wire circuits, three-wire circuits, polyphase generation, motor-generators, 1200 volts from converters, converters vs. motor-generators, mercury gas rectifiers.

**Three-phase System:**

Generation and transmission, number of substations, two overhead trolleys, 750, 3000, 6000 volts, 15, 25, 60 cycles, transformation at substations or on locomotives.

**Single-phase Systems:**

Generation, single- or three-phase; transformation if required for transmission, substations if required, no attendants, one overhead trolley, 600, 3000, 6000, 11,000, 15,000 volts, 15, 25, 60 cycles.

**Combinations of Electric Systems:**

Leonard-Oerlikon, direct-current single-phase, three-phase direct-current, single-phase, three-phase, direct single-phase, three-phase, single-phase rectifier plan, gas-electric plan, storage batteries.

**Interchangeable or Universal Systems.**

**Relative Advantages of Each System:**

Generating equipment, power transmission, railway motor equipment, cost of complete equipment, operation and maintenance.

**Conclusions and Opinions.**

**Literature.**

## CHAPTER IV.

# ELECTRIC SYSTEMS AVAILABLE FOR TRACTION.

### CLASSIFICATION.

The development of electric traction systems preceded an extensive use of electric power for railway train service. The progress made between 1890 and 1910 will be outlined, and a summary of the present status of each system will precede the details of the development.

**Commercial systems** are first classified.

Direct-current, 600, 1200, 1500, or 2000 volts.

Three-phase, alternating-current, 3000 or 6000 volts.

Single-phase, alternating-current, 3000, 6000, 11,000, or 15,000 volts.

Combinations of these three systems; their use with current rectifiers; their use with steam or gasoline power, etc.

The choice of an electric system is necessary in every electrification, and obviously, each system has its advantages. The final choice, often a compromise, is influenced by existing systems, by manufacturers' standards, by financial interest, and by the real needs of the situation.

**Essential features** which should receive consideration are:

Service—trolley, interurban railway, or railroad.

Traffic—density, frequency, weight of individual trains.

Power characteristics—source, cycles, conversion, transformation.

Power plant load factor—the effect of diversity of load on economy when heavy individual train loads are widely separated.

Cost of electrical equipment—motor cars and locomotives, feeders and contact lines, and substations.

Cost of maintenance—substation equipment, transmissions, and motors per ton-mile or per passenger-mile.

Distance between stops, and total distance, are not essential features.

### DIRECT-CURRENT SYSTEM FOR RAILWAYS.

**Direct-current systems** now have the following status: With a potential between the trolley or the third-rail and the track rails, direct-current at 600 volts is used by all street railways, most of the interurban railways; the New York City terminals of the New York Central, the New Haven, the Pennsylvania, and the Long Island Railroads; also for one important tunnel where there are heavy grades on the Baltimore & Ohio, and one on the Michigan Central Railroad. The only example in common long-distance passenger-train service is on the West Jersey and Seashore Railroad, a 65-mile road between Camden and Atlantic City.

All subway lines, elevated roads, and terminal railways, in local passenger service, have adopted the direct-current, 600-volt, third-rail system.

Direct current at 1200 volts is now usedby 14 American interurban railways, and by 7 European railways. No railroad yet uses 1200 volts for train service, except the Southern Pacific, with an overhead trolley, for its suburban work, partly on city streets, in and near Berkeley and Oakland, California.

Direct current when used by railroads at low voltages requires an excessive investment and a large loss in the transmission, conversion, and transformation of the electrical energy. Direct current at 1200 to 2000 volts allows an increase in the length of the electrical zone, since the loss in the local contact line is reduced.

**The generation** of energy, for the direct-current, 600- or 1200-volt system, for railway-train service, is not as direct current, but as three-phase alternating current; the latter is generally transmitted at high voltage, then transformed to low voltage, and then changed by rotary machinery to direct current, at 600 or 1200 volts, in substations along the route of the railway.

## OUTLINE OF THE DEVELOPMENT OF DIRECT-CURRENT SYSTEMS.

**Generation, transmission, and utilization of direct current** came first. The development began with 75 volts, was soon 200, and, by the year 1895, had increased to 600 volts, a standard which is now used by over 95 per cent. of the street, interurban, and elevated railways of this country.

The 1200-volt, direct-current, two-wire system, first tried in 1907, requires that the insulation be doubled at generators, trolley wires, controllers, motor-windings, and commutators. Voltages which are higher than 600 volts are not used across the commutators of railway motors or rotary converters. At the substations, two 600-volt generators, or two 600-volt rotary converters are connected in series. On the cars, two 600-volt, interpole-type motors, each insulated for 1200 volts, are connected in series, and each pair is arranged for series-parallel operation.

Central California Traction Company is the exception. It uses four 1200-volt, G. E., No. 205 motors, rated 75 h. p. each, for 35-ton passenger cars. In the city streets, 600 volts are used; on the right-of-way current is collected at 1200 volts, from a 40-pound third-rail. This road has 7 motor cars.

A table which follows, on the development at higher direct-current voltages since 1904, shows that about 20 small railways in Europe have adopted the two-wire 750- to 2000-volt direct-current system.

**Three-wire systems** are those in which the track is used as a neutral line, not for the return of the main current. Track feeders and bonding may be reduced. Electrolytic troubles may be done away with. The

full advantage of the three-wire system is realized when the load on the two sides is balanced, and the minimum current is returned via the neutral or tracks. A balance of the load on the feeders can be obtained by splitting the various sections and dividing the grades or heavy service portions of the line, by means of double-throw switches.

The three-wire, direct-current system, with 600 volts between the trolley and the track, was used for a short time, in 1894, by W. C. Gotshall, at St. Louis, on a road with 250 cars. The system was also used in Portland, Oregon, and in Pittsburg; see St. Ry. Journ., July, 1899, p. 426. City and South London, see St. Ry. Journ., Aug. 16, 1902, p. 229. With the introduction of three-phase, high-voltage transmissions, about 1896, the use of 1200-volt, three-wire systems decreased rapidly.

Within the past ten years the two-wire and the three-wire 1200-volt system has again received serious consideration, as is shown below.

DIRECT-CURRENT RAILWAYS USING 750 TO 2000 VOLTS. EUROPEAN.

| Name of railway or location. | Name of country. | Installation by. | Voltage. | Mileage. | Reference or notes. |
|---|---|---|---|---|---|
| City & South London | England | .......... | 500* | 15 | Electric Review, Feb. 13, 1909. |
| Grenoble-Charpareillan | France | Thury | 600* | 26 | E. R. J., Oct. 31, 1903. |
| Iselle Mining District | France | Thury | 2,000 | ....... | 55-ton, 550-h.p. locomotive |
| St. Georges-La Mure | France | Thury | 1,200* | 20 | To be changed to 2400-volt, two-wire. |
| Paris North-South | France | Thury | 750* | 4 | London Elect., Dec. 9, 1910. |
| Mozelle-Maizieres Saint Marie. | France | Siemens | 2,000 | 9 | Described in Chapter VIII. Third-rail line. |
| Villefranche-Bourg Madame | France | Alioth | 850 | 34 | |
| Cologne-Bonn | Germany | Siemens | 990 | 18 | S.R.J., May 2, 1908. |
| Berlin Elevated | Germany | Siemens | 750 | 16 | .......................... |
| Castellamare | Germany | Siemens | 825 | 12 | .......................... |
| Anhalt Coal | Germany | Siemens | 900 | 4 | .......................... |
| Stuttgart-Dagerloch | Germany | Siemens | 800 | 18 | Shunt motors. Regeneration. |
| Hamburg City | Germany | .......... | 800 | ....... | Year 1909. |
| Salzberg Tramway | Germany | A.E.G | 900 | 8 | 1909. |
| Nuremberg | Germany | .......... | 550* | 13 | S.R.J., July 1, 1905, p. 15. |
| Berchtesgaden | Austria | .......... | 1,000 | 8 | Nine 120-h.p. cars. |
| Vienna City | Austria | Krizik | 1,500* | 18 | S.R.J., Nov. 3, 1906. |
| Tabor-Bechyne, | Austria | Krizik | 700* | 16 | S.R.J., Dec. 10, 1904. |
| Trient-Male | Austria | .......... | 800 | 40 | .......................... |
| Montreux-Bernois | Swiss | Alioth | 850 | 39 | S.R.J., Nov. 13, 1909. |
| Bellinzona-Mesocco | Swiss. | Rieter | 1,500 | 19 | S.R.J., Nov. 4, 1905. |
| Briantae Electric | Italy | Gen. Elec. | 1,200 | 16 | .......................... |
| Bresciana Electric | Italy | Gen. Elec. | 1,200 | 33 | 18 cars; 45-h.p. motors. |

* The star indicates that the three-wire system is used.
The voltage given is that between the trolley and the rail.
Complications are experienced with lighting, compressor, controller, and contactor circuits.
Four 550-volt motors are used in series, on 2000 volts. Series-parallel control is abandoned.
The roads listed are city or interurban trolley lines.

DIRECT-CURRENT RAILWAYS USING 1500 VOLTS. AMERICAN.

| Name of railway. | Mile-age. | Equip-ment. | Motor h.p. | Elec. Ry. Jour. reference. |
|---|---|---|---|---|
| Piedmont & Northern........... | 125 | 23 MC | 4–90<br>4–14L | May 20, 1911, p. 885. |

Ten 500-kw. motor-generator sets are to be used. Locomotives weigh 55 tons and will haul 800-ton freight trains on long steep grades between Charlotte, N. C., and Greenwood, S. C. Westinghouse equipment is used.

DIRECT-CURRENT RAILWAYS USING 1200 VOLTS. AMERICAN.

| Name of railway. | Mile-age. | Motor cars. | Motor h.p. | Elec. Ry. Journal references. |
|---|---|---|---|---|
| Indianapolis & Louisville............ | 42 | 10 | 4–75 | Jan. 4, 1908, p. 4. |
| Pittsburg, Harmony, Butler & New C. | 77 | 16 | 4–75 | Jan. 16, 1909, p. 92 |
| California Midland................. | 2 | 2 | 4–75 | July 13, 1907. |
| Central California Traction........... Stockton-Lodi, third-rail. | 49 | 10 | 4–75 | April 17, 1909, p. 738. |
| Southern Pacific Co., Oakland, Cal. . | 35 | 65 | 4–125 | Feb. 4, 1911. |
| San Jose & Santa Clara, California . . | 25 | 39 | ....... | .................... |
| Milwaukee Electric Ry............... | 68 | 15 | 4–125 | March 13, 1909, p. 460. |
| Waukesha Beach to Watertown. St. Martins to East Troy. St. Martins to Burlington. | ...... | 15 | 4–75 | July 16, 1910, p. 102. |
| Southern Cambria Ry., Johnstown, Pa. | 24 | 4 | 4–75 | Sept. 3, 1910. |
| Aroostook Valley R. R., Maine...... | 12 | 2 | 4–50 | .................... |
| | | 1 | 4–75 | .................... |
| Albuquerque Traction Co., N. M... | 5 | 6 | 4–50 | 3-wire system. Abandoned in 1907. |
| Sapulpa, Oklahoma Interurban ..... | 9 | 7 | 4–50 | .................... |
| Washington, Baltimore & Annapolis | 60 | 30 | 4–75 | See single-phase roads. |
| | | 3 | 4–125 | |
| Shore Line Electric Ry., New Haven | 52 | 10 | 4–50 | Dec. 4, 1909, p. 1133. |
| | | 2 | 4–75 | May 20, 1911. |
| Meriden, Middleton & Guilford, Conn. | 20 | ...... | ....... | |
| Fort Dodge, Des Moines & Southern. . | 70 | 6 | 4–75 | Jan. 14, 1911, p. 81. |
| | | 4 | 4–125 | |
| Total—14 roads.................. | 550 | 247 | | |

Equipment for the above trolley line lines was furnished by the General Electric Company, which had advocated the 1200-volt system since 1908, when it abandoned the manufacture of single-phase series-compensated and series-repulsion motors.

General Electric Company's annual report, January, 1909, stated:

"The continued successful operation of our 1200-volt direct-current railway apparatus fully demonstrates the reliability of this most valuable system, which fulfils the requirements of railway companies for extensions and for interurban service beyond the economical limits of 600-volt distribution, avoiding the complication incidental to single-phase, alternating current equipments when operated over direct-current lines."

"Prior to January, 1911, over 85,000 h. p. of 1200-volt direct-current G. E. motor equipment was in service or on order."

### DIRECT-CURRENT SYSTEM, WITH POLYPHASE GENERATION.

Generation and transmission of *three-phase current* at 60, 35, or 25 cycles, at high voltages, and its utilization, after its transformation, and its conversion by rotary converters, to *direct current* at 600 volts, at many substations, for electric railway service, was an important development. A historical outline is presented.

### DEVELOPMENT OF POLYPHASE CURRENT FOR DIRECT-CURRENT RAILWAYS.

Taftsville, Conn., 2500 volts, 300 h. p., 3.5 miles, 1894.

One 50-cycle synchronous motor, belted to a 250-k. w. railway generator, was installed by the Baltic Power Company, under the direction of Dr. Louis Bell and Mr. H. E. Raymond, and furnished power to about 16 cars on 16 miles of road, for the Norwich Street Railway.

Lowell, Mass., 5500 volts, 800 h. p., 15 miles, 1895.

This is said to be the first three-phase transmission plant with direct-current converters. Four 75-k. w., 900 r. p. m., 30-cycle converters were installed for railway work. The power was used by the Lowell & Suburban Street Railway.

Portland, Oregon, 6000 volts, 2000 h. p., 13 miles, 1895.

Two 450-k. w. rotary converters on a 33-cycle, three-phase circuit were used for railway work. The cycles were adapted for rotary converters and also for the arc and incandescent lighting service of this pioneer company. Dr. Louis Bell, S. R. J., Sept., 1898, calls this the first railway converter installation.

Sacramento, California, 11,000 volts, 3000 h. p., 23 miles, 1895.

Two 60-cycle synchronous motors ran railway generators.

Fresno, California, 19,000 volts, 900 h. p., 35 miles, 1895.

A 60-cycle motor ran a railway generator.

Bakersfield, California, 10,000 volts, 1000 h. p., 12 miles, 1896.

One 100-k. w., 60-cycle synchronous converter was used.

Niagara Falls, N. Y., 11,000 volts, 3000 h.p., 21 miles, 1896. 22,000 volts, 6,000 h.p. 21 miles, 1899. 60,000 volts, 14,000 h.p., 160 miles, 1907. Two 450-kilowatt, 600-volt, 25-cycle converters, placed in service at Niagara Falls, and at Buffalo, in 1896, were quite successful. They marked a decided improvement over 60-cycle converters, most of which, up to the year 1902, were failures.

Minneapolis, Minn., 13,200 volts, 4000 h. p., 9 miles, 1897.

Electric power aggregating 4200 k. w. was transmitted to three substations in

Minneapolis and St. Paul, entirely underground, in three-phase, paper-insulated cables. Six 600-k.w., 35-cycle railway converters were placed in service. The engineering work was carried out by the writer.

Mechanicsville, N. Y., 12,000 volts, 5000 h. p., 14 miles, 1898.
Use of 38-cycle power for electric railway at Schenectady.

Helena, Montana, 45,000 volts, 8000 h.p., 57 miles, 1898.
Two 60-cycle, 300-k.w. converters were used in Butte.

Redlands, California, 33,000 volts, 4000 h. p., 80 miles, 1898.
One 100-k.w., 50-cycle converter was used at Los Angeles.

Chicago & Milwaukee Railroad, 5500 volts, 650 h.p., 9 miles, 1899.
Four 125-k.w., 25-cycle converters were used. E. W., Apr. 8, 1899.

Union Traction Company, 22,000 volts, 4000 h.p., 30 miles, 1900.
This was for a modern interurban railway in Indiana.

Snoqualmie Falls Company, 33,000 volts, 8000 h. p., 40 miles, 1900.
Four 60-cycle, railway rotary converters were used in Seattle and Tacoma.

Metropolitan Street Railway, N. Y., 6600 volts, 15,000 h. p., 1901.
This became at once the largest installation. Twenty-six 900-k. w. converters were installed. The use of 25 cycles was now established.

## GENERATORS FOR 1200- TO 1500-VOLT, DIRECT-CURRENT SYSTEM.

**1200-volt rotary converters** are not used for heavy railroad work. At the present state of the development, two 600-volt generators or two rotary converters are operated in series, in 1200- to 1500-volt systems. The generators are designed as follows:

1. *Large interpoles* are used, which are far below saturation until a very heavy overload is reached; and the poles must be so proportioned that they will follow any sudden change in load. The interpole coils must not be shunted with resistance or impedance, otherwise they will not be effective on short circuit. The danger from a heavy rush of current due to short circuit will always be greater in 1200-volt railway systems than in a 600-volt system. The danger from flashing at the 600-volt commutator is also large where two generators operate in series as one unit; for, if either commutator should flash in case of a short circuit, then 1200 volts are thrown across the other commutator to flash that commutator; and the disturbance is liable to flash the other machines in the same sub-station and do much more damage than in the case of 600-volt service. In a rotary converter, commutating poles can seldom be made large enough for short-circuit conditions.

2. *A large number of commutator bars* are used between neutral points or brushes, to decrease the flashing tendency in case of a short circuit, as with ordinary 600-volt generators; but 600-volt converters flash viciously on a short circuit, regardless of the number of commutator bars per pole; and what is safe in a generator will not prevent trouble in a converter.

3. *Standard direct-current generator designs* are used for the magnetic field structure. This design embraces a cast iron field yoke and laminated poles. When a short circuit occurs or flashing exists across the brushes,

the fields are quickly demagnetized. In rotary converters the yokes are of steel, which have about four times the conductivity of cast iron for secondary currents, and the pole faces are solid and provided with dampers. This standard design, which is necessary for converters, allows heavy secondary currents to be induced, and these tend to maintain the magnetization and current during flashing or short circuit. The converter is tied to the alternating-current system which can feed excessive current to the commutator; and further, after the alternating-current circuit breaker opens, the flashing with the reduced direct-current field is found to be decidedly severe. The converter may even pull out of the service and drop back again with reversed polarity. This makes in all a relatively bad showing for a converter in case trouble arises. Naturally more short circuits will arise from railway motor flashing and from break-down of insulation with 1200-volt than with 600-volt circuits

Mercury-arc or other types of rectifiers, placed at frequent intervals along the line may be developed, to do away with rotating apparatus and attendants at substations.

## THREE-PHASE ALTERNATING-CURRENT SYSTEMS FOR RAILWAYS.

**Three-phase systems** have the following status: With 3000 or 6000 volts and with 15 and 25 cycles, they are used by three railroads in Europe and one in America, for heavy railway train service. The four roads are here described briefly.

1. Three lines of the **Italian State Railway:**

**Valtellina,** with 67 miles of main track between Lecco, Sondrio, and Chiavenna, was electrificd in 1902, for operation with two 3000-volt trolleys. The equipment, built by Ganz, includes ten 58-ton, 300-h.p. motor cars with coaches and six locomotives. Five to six trains are in service at one time. This road is being extended 25 miles to Milan.

**Giovi Line,** north of Genoa, with 13 miles of double track, and 3.5 per cent. ruling grades, including a 2.6 mile tunnel with a 2.9 per cent. grade, was equipped in 1909 with the 15-cycle, 3000-volt, three-phase system. The equipment built by Westinghouse includes twenty 67-ton, 2000-h. p. locomotives, which are used in pairs to haul 420-ton trains, at 14 or 28 m. p. h., up 2.9 per cent. grades. The service is the heaviest in Europe.

**Savona-Ceva,** or Savona-San Giuseppe Line, 13 miles long, in service since 1909, uses 10 locomotives similar to the Giovi.

**Mt. Cenis Tunnel,** between France and Italy, built in 1910, was equipped with 10 locomotives similar to the Giovi.

2. **Swiss Federal Railway** equipped its Simplon Tunnel and terminal yards, 14 miles of road, in 1907, with the 15-cycle, 3000-volt, three-phase system. The equipment, manufactured by Brown, Boveri & Company,

includes three locomotives, for hauling 730-ton freight trains, at 22 m. p. h., on 0.7 per cent. grades.

In the installations noted above, the 3000 volts are used directly on the motor field windings.

3. **Santa Fe-Gergal road,** in southwestern Spain, a mountain road, 15 miles long, uses five 320-h. p., three-phase, 15-cycle locomotives, built by Brown, Boveri & Company.

4. **Great Northern Railway** electrified, in 1909, 4 miles of main track and 2 miles of terminal track, at the Cascade tunnel, in Washington, using the 6000-volt, three-phase, 25-cycle system. The equipment consists of four 115-ton, 1700-h. p. locomotives which haul 1800-ton trailing loads up the 1.7 per cent. grade at one speed—15 m. p. h.

The complication of the necessary double overhead contact wires had debarred this system from all high-speed interurban railways, and from large railroad switching yards.

## OUTLINE ON DEVELOPMENT OF THREE-PHASE SYSTEM FOR RAILWAYS.

Generation, transmission, transformation, and use of *three-phase* current at 15 and 25 cycles, and at 3000 and 6000 volts, followed the direct-current system, for railway train service.

Alternators, with revolving fields and large transformers for high voltages, had been developed in Europe by 1896. Three-phase induction motors, with and without collector rings, had been developed by Tesla and others, and the time had come for the development of a new system to utilize and adapt this equipment for heavy railroading.

Siemens & Halske exhibited at Chicago Exposition, in 1893, a three-phase, 600-volt, 50-cycle, 1400 r. p. m., 11 to 1 geared, railway motor, which had been used on an experimental track at Charlottenburg.

Brown, Boveri & Company equipped a street railway in Lugano, Italy, in 1896; three mountain railways in Switzerland, in 1898; and an interurban line between Burgdorf and Thun, 26 miles, in 1899. The voltages used were from 500 to 750.

Ganz Electric Company installed this system for railway service between London and Port Stanley, Ontario, 27 miles, in 1905. Two 1100-volt, 65-h. p. motors were used per motor car. Trailers were hauled. The line loss was heavy, and, on the grades at the ends of lines, the motors simply died down or fell out, when overloaded, because of lack of draw-bar pull. Had additional transformer stations been installed, the motor trouble would have been avoided; but this experience showed that, with the low voltage necessarily used with a two-trolley, three-phase system, substations must be frequent. St. Ry. Journ., Dec. 9, 1905, p. 1026.

Ganz Electric Company must, however, be credited with the first real

advance in the application of the three-phase system for railroads. Its initial electrification was in 1902 for the Italian State Railway. The number of cycles used was 15, which was advantageous for the motors. The voltage between the 2 trolleys and the rails was 3000, which voltage has not since been exceeded in Europe. It is a safe pressure for collecting devices from 2 overhead conductors which must be insulated from each other in railroad switching yards, terminals, and bridges; and for the controller and motor wiring; and it is safe for stator and rotor windings of motors on locomotives, but not on motor cars. The 3000-volt three-phase installation required substations 6 miles apart.

Berlin-Zossen tests, made at Berlin in 1903, for the study of high speeds on railways used the three-phase system. Speeds up to 130 m. p. h. were obtained. Experimental motor-car equipments built by Allgemeine Elektricitats-Gesellschaft and by Siemens-Schuckert were designed for 10,000 volts, and 50 cycles. The overhead construction, with three 10,000-volt trolley wires in a vertical plane, would not be practical in railroading.

Brown, Boveri & Company, in 1907, equipped the Simplon Tunnel.

Westinghouse Company of Italy, in 1909 and 1910, equipped the Giovi, Savona-Ceva, and Mt. Cenis Tunnel roads as detailed.

Technical descriptions of all locomotives are given later.

THREE-PHASE RAILROADS—EQUIPMENT AND MILEAGE.

| Name of railroad. | Mileage. | Locomotives. | H.P. per locomotive. | Cycles used. | Trolley voltage. |
|---|---|---|---|---|---|
| Burgdorf-Thun........ | 26 | 3 | 300 | 40 | 750 |
| Italian State: | | 2 | 600 | | |
| Valtellina .......... | 70 | 2 | 1200 | 15 | 3000 |
| | | 2 | 1500 | | |
| Giovi............... | 38 | 20 | 1980 | 15 | 3000 |
| Savona-Ceva........ | 13 | 10 | 1980 | 15 | 3000 |
| Mt. Cenis Tunnel.... | 5 | 10 | 1980 | 15 | 3000 |
| Swiss Federal: | | | | | |
| Simplon 1906....... | 14 | 2 | 1100 | 16 | 3000 |
| 1909............. | | 2 | 1700 | 16 | 3000 |
| Santa Fe-Gergal........ | 15 | 5 | 320 | 15 | 5500 |
| Great Northern........ | 6 | 4 | 1700 | 25 | 6000 |

Street railways and rack and pinion railways are not listed.

Burgdorf-Thun Railway has six 60-h.p. motor cars, each of which hauls one or two coaches. Valtellina Railway has ten 300-h.p. motor cars.

Great Northern locomotive rating is 1900-h.p. with forced draft. The motor voltage is only 500. In the European motor-car and locomotive installations, the full trolley voltage is used directly on the motor fields.

## SINGLE-PHASE ALTERNATING-CURRENT SYSTEMS FOR RAILWAYS.

**Single-phase systems** now have the following status: They are used with 3000 to 11,000 volts, and 15- and 25-cycle alternating currents for many interurban roads and particularly for the haulage of heavy individual train units in trunk-line work. In America, the 11,000-volt, 25-cycle system was selected, in 1906, by the New Haven road for the electrification of its New York-New Haven Division, 73 miles. The first half, to Stamford, is now in successful operation, and plans have been developed for its use in all freight and passenger work for the balance of the division. The single-phase system is also employed by these other roads: Rochester branch of the Erie Railroad, which has used 11,000 volts since 1907; Indianapolis and Cincinnati line, 116 miles, since 1904; Baltimore & Annapolis Short Line, 35 miles; Spokane & Inland Empire Railroad which, since 1906, has used 6000 volts for ordinary freight and passenger service over 162 miles of track; Visalia Division of the Southern Pacific Railway; Denver-Boulder branch of the Colorado & Southern Railroad; Rock Island-Galesburg Division, 52 miles, of the Rock-Island Southern Railroad; and Grand Trunk Railway, for the Sarnia-Port Huron tunnel, where 41 freight and passenger trains per day are hauled thru the yards and up the 2 per cent. grades in the tunnel.

In Europe, the single-phase system has been adopted by these roads: Swedish State Railways; Midland Railway of England; London, Brighton & South Coast; Bavarian State Railway; Mariazell Railroad; Blankenese-Hamburg-Ohlsdorf, and other lines of the Prussian State Railway; Rotterdam-Hague-Scheveningen Railway; Weisental Railway; Bernese-Alps Railway; and Midi or Southern Railway of France. The freight and passenger equipment is tabulated in the tables which follow, and the locomotive equipment is described in Chapter X.

## OUTLINE OF THE DEVELOPMENT OF SINGLE-PHASE SYSTEMS.

**Generation, transmission, and utilization of single-phase, alternating-current,** at 15 and 25 cycles is a recent development.

In September, 1902, at an A. I. E. E. meeting, Mr. B. G. Lamme presented a paper which advocated the use of single-phase alternating-current for railways. The details of the new system had been developed by the Westinghouse Electric and Manufacturing Company, of Pittsburg. This system marked a great advance in the struggle against the economic limitations imposed by the direct-current system on the transfer and distribution of power to widely separated, heavy, individual train units. Heretofore there had been heavy transformation and conversion losses, also an excessive cost for substation equipment, maintenance, and feeders.

Many engineers had been working along this line, the objects of their study being:

1. An alternating-current system for electric railways.
2. Prevention of electrolysis of rail-base metal, water-supply pipes, and of lead casing of the underground feeders, the maintenance of which, and of the track bonding, was excessive.
3. Single-phase feeders from three-phase generators, with a lower investment in feeders for suburban lines and branches of steam railroads.
4. Elimination of the rotary-converter substations.
5. Single-phase motors, without commutators, for railways.

The writer conducted many experiments on a single-phase system in 1898. He was then electrical engineer for the Twin City Rapid Transit Company, which operated 250 miles of electric road in and between Minneapolis and St. Paul. The power system then used was the best. Alternating three-phase current, at 13,200 volts, was transmitted from an 8000-h.p. central station to four substations, each containing from one to three 600-k.w. rotary converters. There were heavy losses in large 660-volt, direct-current feeders, and substation maintenance was expensive.

Experiments were made in Minneapolis. Power was obtained from a 175-kw., 10-cycle, 380-volt, single-phase alternator. (A 660-volt, direct-current, bipolar Edison railway generator was used, and two collector rings slipped over the commutator, were properly connected and insulated.) Power was fed to an ordinary trolley line. Two 15-h.p. Sprague, 600-volt, series, direct-current, "standard" street railway motors were used on an ordinary street car. These direct-current motors were used on the single-phase, alternating-current circuit.

The results from these motors were of course disappointing. The inductive effects with the solid wrot iron fields, the 812 turns of No. 12 wire in series on the two field coils, and the long air gaps, so reduced the input, that the torque and the output of the motor were practically nil. "Weight efficiency" was certainly bad. Sparking and heating existed at the commutator, at any position of the brushes, from the e. m. f. induced by the armature coils short-circuited by the brushes.

Allgemeine Elektricitats Gesellschaft in 1903 used single-phase motors on a public road at Spindlersfield, near Berlin.

Mr. B. J. Arnold, of Chicago, experimented in 1903 with a single-phase, alternating current motor combined with an air compressor. A. I. E. E. proceedings, June, 1902, p. 1003. See locomotive drawings, Western Electrician, Jan. 2, 1904; E. E., 1904, p. 83.

Westinghouse Electric & Manufacturing Company placed the first single-phase system and single-phase railway motor equipment in commercial service in December, 1904, on the Indianapolis & Cincinnati Traction Company's Interurban line. The original 82 miles of track were soon increased to 116 miles.

Four years later there were 1000 miles of single-phase road, equipped with 246 motor cars and 64 electric locomotives, with a capacity of 137,000 h.p. in railway motors. In Europe there were approximately 900 miles in service in December, 1908; and at that date over 250,000 h.p. in single-phase railway motors had been sold in America and in Europe. This represents a most wonderful development.

The installations to the present year are listed. The data were collected by visits, by correspondence, and from descriptive items in technical papers.

SINGLE-PHASE RAILWAYS, 25-CYCLE, SERIES-COMPENSATED MOTORS. AMERICAN.

| Name of railway. | Year opend. | Mile-age. | Trolley voltage. | A.C. D.C. | Equip-ment. | Motor h. p. |
|---|---|---|---|---|---|---|
| **Westinghouse:** | | | | | | |
| Indianapolis & Cincinnati..... | 1904 | 112 | 3,300 | Yes | 25 MC | 4–100 |
| Westmoreland County Traction, Derby to Latrobe, Pa... | 1905 | 7 | 1,200 | No | 4 MC | 4– 50 |
| San Francisco, Vallejo & Napa Valley, California. | 1905 | 34 | 3,300 | No | 9 MC | 4–100 |
| | | | | | 2 MC | 2– 75 |
| Warren & Jamestown........ | 1905 | 26 | 3,300 | No | 6 MC | 4– 50 |
| Long Island R. R.: | | | | | | |
| Sea Cliff Division. | 1905 | 6 | 2,200 | No | 6 MC | 2– 50 |
| Spokane & Inland Empire R.R. | 1906 | 162 | 6,600 | Yes | 25 MC | 4–100 |
| | 1908 | ...... | ......... | ...... | 6 L | 4–125 |
| | 1910 | ...... | ......... | ...... | 8 L | 4–170 |
| Fort Wayne & Springfield..... | 1907 | 22 | 6,600 | Yes | 4 MC | 4– 75 |
| Pittsburg & Butler........... | 1907 | 39 | 6,600 | Yes | 13 MC | 4–100 |
| Erie R.R.................... First steam railroad to use single-phase system, Rochester-Mt. Morris Division. | 1907 | 40 | 11,000 | No | 6 MC | 4–100 |
| Windsor, Essex & Lake Shore. | 1907 | 40 | 6,600 | No | 8 MC | 2–100 |
| | | | | | 1 L | 4–100 |
| New York, New Haven & Hartford, New York Division, 23 miles of 4-track road. | 1907 | 100 | 11,000 | Yes | 41 L | 4–240 |
| | 1908 | ...... | ......... | Yes | 1 L | 4–315 |
| | 1909 | ...... | ......... | Yes | 4 MC | 4–150 |
| | 1910 | ...... | ......... | Yes | 1 L | 2–675 |
| | 1911 | ...... | ......... | Yes | 1 L | 8–174 |
| Harlem River freight yards.. | 1911 | 63 | ......... | No | 14 L | 4–150 |
| | | | | No | 4 MC | 4–150 |
| Visalia Electric Ry., California (15 cycles). | 1908 | 36 | 3,300 | No | 6 MC | 4– 75 |
| | | | | | 1 L | 4–125 |
| Grand Trunk Ry.: | | | | | | |
| Sarnia-Port Huron Tunnel... | 1908 | 12 | 3,300 | No | 6 L | 3–240 |
| Hanover & York Ry., Pa...... | 1908 | 21 | 6,600 | Yes | 5 MC | 4– 75 |
| Baltimore & Annapolis S.L.... | 1908 | 35 | 6,600 | No | 12 MC | 4–100 |
| Colorado & Southern: | | | | | | |
| Denver & Interurban R.R.... | 1908 | 54 | 11,000 | Yes | 16 MC | 4–125 |
| Chicago, Lake Shore & South Bend. | 1908 | 90 | 6,600 | No | 24 MC | 4–125 |
| | | | | | 7 MC | 2– 75 |
| Rock Island Southern: | 1910 | 52 | 11,000 | No | 6 MC | 4–100 |
| Rock Island to Monmouth... | | | | | 4 MC | 4–125 |
| New York, West Chester & Boston. | 1911 | 63 | 11,000 | No | 100 MC | 4–150 |
| Boston & Maine: | | | | | | |
| Hoosac Tunnel............. | 1911 | 25 | 11,000 | No | 5 L | 4–315 |
| Total—20 roads............. | ...... | 1039 | ......... | ...... | 296 MC | ...... |
| | | | | | 86 L | |

Most of the installations are for railroad train service.

SINGLE-PHASE RAILWAYS, 25 CYCLES. AMERICAN.

| Name of railway. | Year opend. | Mile-age. | Trolley voltage. | A.C. D.C. | Equip-ment. | Motors h.p. |
|---|---|---|---|---|---|---|
| **General Electric:** | | | | | | |
| Schenectady Ry.: | | | | | | |
| Ballston Division, (compensated motor). | 1904 | 16* | 2,200 | Yes | 2 MC | 4–50 |
| Illinois Traction Co: | | | | | | |
| Bloomington-Peoria.... | 1905 | 38* | 3,300 | No | 10 MC | 4–75 |
| Springfield-Mackinaw .. | 1907 | 57* | 3,300 | No | 20 MC | 4–75 |
| Toledo & Chicago Ry.... | 1906 | 43 | 3,300 | Yes | 7 MC | 4–75 |
| Milwaukee Electric Ry.: | | | | | | |
| Waukesha-Oconomowoc; Burlington & East Troy. | 1907 | 68* | 3,300 | Yes | 15 MC | 4–75 |
| Richmond & Chesapeake Bay (repulsion motor). | 1907 | 16 | 6,600 | No | 4 MC | 4–125 |
| Anderson Traction, S. C. | 1907 | 20 | 3,300 | Yes | 3 MC | 4–75 |
| New York, New Haven & Hartford, Stamford-New Canaan Branch. | 1908 | 8 | 11,000 | No | 2 MC<br>4 MC | 4–125<br>4–125 |
| Shawinigan Ry., Quebec 30 and 15 cycles. | 1908 | 1 | 6,600 | Yes | 1 L | 4–150 |
| Washington, Baltimore and Annapolis. | 1908 | 87* | 6,600 | Yes | 22 MC | 4–125 |
| Total............. 9 | ...... | 354 | ........ | ....... | 89 MC | .......... |
| Abandoned*....... 4 | ...... | 266 | ........ | ....... | 68 MC | .......... |
| In service......... 5 | ...... | 88 | ........ | ....... | 21 MC | .......... |

General Electric Company used three sizes of single-phase motors. GE-604, 50-h.p.; 605, 75-h.p.; 603, 125-h.p. For data on the latter see A. I. E. E., May 21, 1907, p. 701.

Cost of these alternating-current direct-current motor equipments is stated to have been nearly twice that of direct-current equipment.

A 15-cycle, 400-h.p. experimental locomotive built in 1909 is described under electric locomotives.

General Electric single-phase railway equipments have, in most cases, been discarded, as noted below:

Schenectady Railway claimed unsatisfactory operating results.

Illinois Traction abandoned single-phase equipment, because the motor operation was unsatisfactory, and to standardize the electric power system. Elec. Ry. Journ., Jan. 22, 1910, p. 142.

**Milwaukee Electric Railway and Light Company** abandoned the system in 1909. President John I. Beggs is quoted:

"I have been forced to this action very reluctantly, as this type of apparatus is, in my judgment, a commercially operating necessity thru sparsely settled territory on long outlying lines, the amount of business on which does not justify the maintenance of substations at frequent intervals with constant manual attention. The

alternating-current equipment does fairly well when operated as single units, but on our lines, during seasons of heavy traffic, we are compelled to attach anywhere from one to three large trailers which our single-phase apparatus had not the power of starting."

"We are substituting for the alternating-current equipment, the 600–1200-volt system, which reduces very considerably the objectionable features of direct-current substations at such frequent intervals. We have arranged for thirty 4-motor, 125-h.p., direct-current equipments of this type (on 40-ton, 53-foot cars) to replace the fifteen 4-motor, 75-h.p. alternating-current equipments (on 41-ton, 53-foot cars) operated by us for nearly two years past."

(In other words, the 75-h.p. electric motors were too small for the overloads.)

The watt-hours per ton-mile were materially less for the alternating-current than for the direct-current system. References: E. R. J., May 1, 1909, p. 823. S. R. J., Aug. 3, 1907, p. 158; March 13, 1909, July 16, 1910.

**Washington, Baltimore & Annapolis Railway** installed the single-phase system in 1908 for its interurban line, but abandoned it in 1909 for the 1200–volt direct-current system. The road was placed in the hands of a receiver, who reported:

"The cause of the present condition can be summed up by stating that the amount of the company's present liabilities, for which it has not been able to issue securities, is made up entirely of the amount which it has been required to put into its construction account, and the deficit caused by the large percentage of operating expenses under the alternating-current system."

The writer investigated, and found that the road, which runs from Washington to Baltimore, has 33.5 miles of double track, and also a 15-mile single-track branch from the middle of the line to Annapolis. The road, except in the cities, is largely on a private right-of-way. It began electrical operation in February, 1908, as a single-phase trolley line. Motors were number 603-A, repulsion type, four 125-h.p. units per car, with plain rheostatic control on 600-volt direct-current, and with potential control, two motors being in series, on 113 to 450-volt single-phase circuits.

The Washington terminal was 2.75 miles from the heart of the city, and a transfer, with delays, was required to reach the city via the local trolley cars, a handicap which accounted for the fact that the traffic and earnings fell short of the estimates.

At Washington, the trolley runs in an underground conduit. The complication was indeed great, with the direct-current system, the alternating-current system, the overhead trolley, and the conduit trolley. Moreover, the limited strength of the conduit and track yokes would not support a 45-ton trolley car, and smaller cars were required to take 50-foot radius curves in Baltimore and Washington. The large interurban cars were sold, viz.: 23 cars, 62-foot, 66-seat, 57-ton with 4–125-h.p., alternating motors, and replaced by 33 cars, 50-foot, 54-seat, 39-ton, with 4–75-h.p., direct-curren motors. Vibration on the alternating motors was excessive when the load was heavy, and caused open circuits in armature leads. Some bar winding connections had to be riveted. Vibration even destroyed the cast-steel gears. The alternating-current motors had to be nursed. Sparking was bad, and required frequent commutator turning. Brush expense was heavy. Carbon dust in the motor case caused many short circuits or flash overs. Brush-holder losses and cleaning entailed heavy maintenance expense.

One of the above alternating-current equipments was redesigned in 1909, with new contactor boxes, simplified control, drop-out overload contactors, a speed limit

relay, and one transformer in place of two. Weight was decreased over four tons. These early troubles were very interesting.

The company in 1910 adopted the 600–1200-volt direct-current system for the city and interurban sections of the line and cars now run into each city. The 7 single-phase transformers formerly used were sold. Five new substations contain sixteen 300-kw., 600-volt rotary converters connected two in series, in pairs. The saving in cost of power, after the change, was 10 per cent. per car-mile in favor of the 1200-volt direct-current system. Since the advance of fares, March 1, 1910, net earnings have increased.

SINGLE–PHASE RAILWAYS, 25 CYCLES. EUROPEAN.

| Name of railway. | Name of country. | Year opend. | Mileage. | Trolley voltage. | Equipment. | Motor h. p. |
|---|---|---|---|---|---|---|
| **Westinghouse:** | | | | | | |
| Midland | England | 1908 | 23 | 6,600 | 1 MC | 2–150 |
| Thamshavn-Lokken | Norway | 1908 | 36 | 6,600 | 3 L | 4– 40 |
| | | | | | 1 MC | 2– 40 |
| Swedish State: | Sweden | 1905 | 7 | 3,300 | 1 L | 2–150 |
| Stockholm. | | | | 18,000 | 1 L | 3–115 |
| | | | | 18,000 | 2 MC | 2–120 |
| Tergnier-Anizy | France | 1909 | 21 | 3,300 | 3 L | 2– 40 |
| | | | | | 3 MC | 2– 40 |
| Roma-Civita-Castel-lana. | Italy | 1905 | 25 | 6,600 | 3 L | 4– 40 |
| | | | | | 8 MC | 2– 40 |
| Salerene-Pompeii | Italy | 1908 | 19 | 6,600 | 20 MC | 2– 40 |
| Brembana Valley | Italy | 1907 | 19 | 6,000 | 5 L | 4– 75 |
| **Siemens—Schuckert:** | | | | | | |
| Midland | England | 1908 | 23 | 6,600 | 2 MC | 2–175 |
| Swedish State | Sweden | 1905 | 7 | 18,000 | 1 L | 3–110 |
| Rotterdam-Hague-S | Holland | 1908 | 48 | 10,000 | 25 MC | 2–175 |
| Prussian State: | | | | | | |
| Blankanese-Ohlsdorf | Germany | 1907 | 17 | 6,000 | 14 MC | 2–125 |
| Oranienburg | | 1909 | 2 | 6,000 | 1 MC | 2–175 |
| Haute-Vienne | Austria | 1910 | ...... | 10,000 | 35 MC | 4– 60 |
| St. Polten-Mariazell | Austria | 1909 | 67 | 6,600 | 17 L | 2–250 |
| Parma Provincial | Italy | 1909 | 40 | 4,000 | 10 MC | 2– 75 |
| | | | | | 8 MC | 1– 60 |
| Roma-Civita-Castel-lana. | Italy | 1906 | 25 | 6,600 | 4 L | 4– 40 |
| | | | | | 4 MC | 2– 40 |
| **A. E. G.** (Winter-Eichberg): | | | | | | |
| Prussian State: Spindlersfeld. | Germany | 1903 | 3 | 6,000 | 2 MC | 2–100 |
| | | | | | 2 MC | 2–200 |
| Oranienburg, Berlin. | Germany | 1906 | 2 | 6,000 | 1 L | 3–350 |
| | | | | | 1 L | 2–350 |
| Blankanese-Ohlsdorf | Germany | 1908 | 17 | 6,000 | 54 MC | 3–115 |
| | | | | | 42 MC | 2–200 |

SINGLE-PHASE RAILWAYS, 25 CYCLES. EUROPEAN.—Continued.

| Name of railway. | Name of country. | Year opend. | Mile-age. | Trolley volts. | Equip-ment. | Motor h.p. |
|---|---|---|---|---|---|---|
| Swedish State: | | | | | | |
| Stockholm......... | Sweden... | 1905 | 5 | 6,500 | 2 MC | 2–115 |
| Thamshavn-Lokken .. | Norway... | 1908 | 36 | 11,000 | 2 MC | 4– 80 |
| Albtal Ry.: | Germany . | 1909 | 34 | 8,000 | 4 L | 4– 85 |
| Karlsruhe-Herrenalb.. | | | | | 7 MC | 2– 85 |
| Padua-Fusina........ | Italy ..... | 1909 | 22 | 6,000 | 13 MC | 2– 80 |
| Naples-Piedimonte... | Italy..... | 1909 | 35 | 10,000 | 2 L | 4– 80 |
| | | | | | 9 MC | 4– 80 |
| Pamplona-Sanguesa... | Spain..... | 1909 | 43 | 6,000 | 5 MC | 4– 80 |
| London, Brighton & | England.. | 1909 | 62 | 6,600 | 16 MC | 4–115 |
| South Coast. | | 1910 | .. | ..... | 30 MC | 4–150 |
| **Oerlikon:** | | | | | | |
| Valle-Moggia: | Swiss..... | 1907 | 17 | 5,500 | 3 MC | 4– 60 |
| Locarno-Bignasco .. | | | | | 1 L | |
| **Brown-Boveri:** | | | | | | |
| Seethal Railroad: | | | | | | |
| Lucerne-Wildegg ... | Swiss..... | 1909 | 33 | 5,000 | 10 MC | 4–100 |

SINGLE-PHASE RAILWAYS, 15 CYCLES. EUROPEAN.

| Name of railway | Name of country. | Year opend. | Mile-age. | Trolley voltage. | Equip-ment. | Motor h.p. |
|---|---|---|---|---|---|---|
| **Westinghouse:** | | | | | | |
| Lyons Tramways....... | France... | 1909 | 27 | 6,600 | 15 MC | 2– 50 |
| Midi, or Southern ...... | France... | 1910 | 70 | 12,000 | 6 L | 2– 800 |
| | | | | | 30 MC | 4– 125 |
| **Bergmann:** | | | | | | |
| Prussian State: | | | | | | |
| Magdeburg-Leipzig | Germany | 1910 | 23 | 10,000 | 1 L | 1–1500 |
| **Siemens—Schuckert:** | | | | | | |
| Bavarian State: | | | | | | |
| Murnau-Oberammer-gau. | Germany | 1905 | 14 | 5,500 | 2 L | 2– 175 |
| | | | | | 4 MC | 2– 100 |
| Prussian State: | | | | | | |
| Magdeburg-Leipzig ... | Germany | 1910 | 23 | 10,000 | 1 L | 1– 800 |
| | | | | | 1 L | 1–1100 |
| | | | | | 1 L | 1–1800 |
| | | | | | 1 L | 2–1250 |
| Baden State: | Germany | 1909 | 37 | 10,000 | 10 L | 2– 525 |
| Weisental-Basel-Zell .. | | | | | 2 L | 2–1200 |

SINGLE-PHASE RAILWAYS, 15 CYCLES. EUROPEAN.—Continued.

| Name of railway. | Name of country. | Year opend. | Mile-age. | Trolley voltage. | Equip-ment. | Motor h.p. |
|---|---|---|---|---|---|---|
| Vienna-Baden | Austria | 1905 | 46 | 10,000 | 20 MC | 4– 60 |
| Waitzen-Budapest-Godollo. | Austria | 1909 | 36 | 10,000 | 4 L | 4– 240 |
| | | | | | 11 MC | 2– 150 |
| Seebach-Wettingen | Swiss | 1907 | 13 | 15,000 | 1 L | 6– 225 |
| Bernese-Alps | Swiss | 1910 | 52 | 15,000 | 3 MC | 4– 220 |
| | | | | | 2 L | 2–1000 |
| Rhatisch Mountain | Swiss | 1911 | 46 | 10,000 | 1 L | 1– 600 |
| Swedish State | Sweden | 1911 | 93 | 15,000 | 2 L | 1–1000 |
| | | | | | 13 L | 2–1000 |
| **A.E.G.** (Winter-Eichberg): | | | | | | |
| Rjukan | Norway | 1910 | 29 | 10,000 | 3 L | 4– 125 |
| | | | | | 2 L | 2– 125 |
| Prussian State: Magdeburg-Leipzig. | Germany | 1910 | 23 | 10,000 | 1 L | 1–1000 |
| | | | | | 1 L | 1– 800 |
| | | | | | 1 L | 2– 950 |
| Bavarian State: Saltzburg-Berchtes-gaden. | Germany | 1911 | 30 | 10,000 | ...... | ........... |
| Midi or Southern | France | 1909 | 70 | 12,000 | 1 L | 2– 800 |
| Bernese Alps | Swiss | 1909 | 52 | 15,000 | 1 L | 2– 800 |
| Mittenwald | Austria | 1910 | 69 | 10,000 | 6 L | 1– 800 |
| Vienna-Pressburg | Austria | 1911 | 42 | 10,000 | 3 L | 1– 800 |
| | | | | | 5 L | 1– 600 |
| **Oerlikon:** | | | | | | |
| Swiss Federal: Seebach-Wettingen. | Swiss | 1905 | 11 | 15,000 | 1 L | 4– 500 |
| Bernese Alps | Swiss | 1909 | 52 | 15,000 | 1 L | 2–1000 |
| Prussian State | Germany | 1910 | 19 | 10,000 | 1 L | 1–1000 |
| Rhatisch Mountain | Swiss | 1911 | 48 | 10,000 | 1 L | 1– 600 |
| | | | | | 3 L | 1– 300 |
| **Brown-Boveri:** | | | | | | |
| Baden State | Germany | 1909 | 33 | 10,000 | 2 MC | ........... |
| Vienna-Baden | Austria | 1907 | 46 | 10,000 | 2 L | 4– 40 |
| Martigny-Orsieres | Swiss | 1909 | 12 | 8,000 | 4 MC | 4– 90 |

Siemens-Schuckert Company has sold prior to 1909, single-phase 15- and 25-cycle railway motors aggregating 33,490 h.p.; prior to September, 1910, 105,000 h.p.

Allgemeine Elektricitats Gesellschaft had sold, prior to 1909, single-phase, 15- and 25-cycle railway motors aggregating 42,480 h.p., and prior to January, 1911, 100,000 h.p.

Prussian, Swiss, Sweden, and Austrian State Railways changed in 1910 from 25- to 15-cycles.

Seebach-Wettingen was abandoned in 1909. Two electric locomotives ran 78,000 miles, but traffic was too light for economical electrical operation.

SUMMARY OF ALL SINGLE-PHASE RAILWAYS.

| 25-cycle. | Manufacturer. | Mileage. | Locomotives. | Motor cars. | Roads. |
|---|---|---|---|---|---|
| American...... | Westinghouse . | 1003 | 86 | 290 | 19 |
| American...... | Gen. Electric. . | 88 | 1 | 21 | 5 |
| European..... | Westinghouse . | 150 | 16 | 35 | 7 |
| European ..... | Siemens....... | 229 | 22 | 99 | 8 |
| European ..... | A.E.G........ | 259 | 8 | 187 | 9 |
| European ..... | Oerlikon...... | 17 | 1 | 3 | 1 |
| European ..... | Brown........ | 45 | 0 | 10 | 2 |
| Total....... | ............... | 1791 | 134 | 645 | 51 |
| Net ...... | ............... | 1676 | ............ | .......... | 44 |

| 15-cycle. | Manufacturer. | Mileage. | Locomotives. | Motor cars. | Roads. |
|---|---|---|---|---|---|
| American ..... | Westinghouse . | 36 | 1 | 6 | 1 |
| European ..... | Westinghouse . | 97 | 6 | 45 | 2 |
| European ..... | Siemens....... | 360 | 41 | 38 | 9 |
| European ..... | A.E.G........ | 315 | 24 | 0 | 7 |
| European ..... | Oerlikon...... | 119 | 6 | 0 | 3 |
| European ..... | Brown........ | 91 | 2 | 6 | 3 |
| European ..... | Bergman...... | 23 | 1 | 0 | 1 |
| Total....... | ............... | 1041 | 81 | 95 | 26 |
| Net ...... | ............... | 735 | ............ | .......... | 16 |
| Grand total net | ............... | 2399 | 202 | 734 | 60 |

## COMBINATIONS OF ELECTRIC SYSTEMS.

Combination, and mixed systems are noted briefly.

1. **Leonard** has designed a system which uses single-phase alternating current on the contact line, which is converted on the locomotives, by a high-speed light-weight motor-generator set, to direct current for the motors. The generator field strength is varied to provide ideal control. The scheme is used by important mine hoists, by battle ships, and for rolling-mill work. One locomotive was built by the Oerlikon Company. Its disadvantage is in the weight of the electrical equipment per h.p.; while the advantages claimed are efficiency of the system and the perfect control of the speed and torque of the motors.

This motor-generator plan, and the rectifier plan, may be used when three-phase 60-cycle power must be used. The conversion of 60-cycle current to direct current, on the locomotive, presents many handicaps.

Leonard, A. I. E. E., July, 1892; St. Ry. Journ., June 7, 1902, p. 735. See description of Leonard-Oerlikon locomotives, which follows.

2. **Direct current and single-phase current** are used, as on the New York, New Haven & Hartford Railroad between New York City and Stamford, direct current from the 600-volt third-rail for local and terminal service, and single-phase alternating current at 11,000 volts for trunk-line service outside of New York City. The combination requires the use of alternating-current, single-phase commutator motors.

3. **Three-phase direct-current motors** are used when both currents are supplied for railway service. The field, or primary, of the motor is then the stator. One of the star-connected three-phase legs or windings is rearranged and utilized for excitation with direct current, while the other two, in series with the first, are utilized as compensation windings to assist direct-current commutation. The rotor may be an ordinary direct-current armature with three-phase tappings to 3 or 4 slip rings. The field and armature are connected in series. On alternating current the brushes must be lifted from the commutator and cascade operation would not be practical, except by placing motors in series. A three-phase, 600-volt, 1000-ampere, 25-cycle, 730-r. p. m. motor, on direct current, could be rated at 53 per cent. voltage, full current and 62 per cent. speed. London-Pt. Stanley (Ontario) Railway, a 27-mile road, built in 1905, used a three-phase, direct-current system. St. Ry. Journ., Dec. 9, 1905, p. 1026. Wilson and Lydall, "Electrical Traction," Vol. II, p. 46.

4. **Single-phase current** for variable-speed service from one of two trolleys, and of *three-phase* current for 1-speed thru-passenger and freight service, is used. Example: Stansstad-Engelberg Railway, Switzerland.

5. **Direct-current** at 600 or 1200 volts from a third-rail; *single-phase* current from one trolley; and *three-phase* current from two trolleys, could be used for trains on the same section of track, with power supplied from the same three-phase bus-bar at the power station; and from the same transmission line and transformers, which may feed both rotary converters and high-voltage contact lines.

6. **Rectifier plans** include a single-phase, alternating-current system, a 12,500-volt overhead line, a locomotive on which a special permutator converts the power into direct current at an e. m. f. adjustable at will between zero volts and 600 volts, and the use of power by ordinary direct-current motors. (The permutator is a revolving commutator.)

Paris, Lyons & Mediterranean Railway is now trying this permutator, or rotating commutator, on a single-phase locomotive. See technical description of the locomotive which follows in Chapter IX.

7. **Mercury arc rectifiers,** which convert single-phase alternating current to direct current without the use of rotating apparatus, may be placed at

intervals along the railway line or on the locomotive. This rectifier requires 25 or higher cycles. It may prove to be highly desirable, in electric systems.

8. **Steam or gasoline** may be combined with electric power. A prime mover on the car, or locomotive, may drive a generator, which in turn may drive motors connected to the axles.

The Glasgow steam-turbine locomotive has been described, page 81.

**General Electric Company's gasoline-electric cars** are used for light service on branch lines. A gasoline engine is direct-connected to a very high-speed direct-current, variable-voltage generator. The fields of the generator are energized by a separate constant voltage exciter, controlled by a Tirrill regulator. The generator delivers current to the four 90-h. p., 600-volt standard-geared railway motors on each axle. The gasolene engine runs continually. It is started by means of compressed air. The entire control is by means of the Leonard plans of varying the field and voltage of the generator. The simplest kind of controller is used and the efficiency of control is high. Where the car can run on a 600-volt trolley line the gasoline engine is taken out of service.

9. **Storage batteries** are not yet used for railway trains. Developments are being made for light traffic having in view a decrease in peak loads, improvement in motor economy during acceleration by using voltage variation to prevent rheostatic losses, and the elimination of about 50 per cent. of the power plant and all line and substation expenditures.

The objections to storage batteries are the high first cost; added dead weight; chemical deterioration; destruction by shock in passing over switch work and in small collisions; time lost in charging the batteries; an efficiency of 50 to 60 per cent. when new; maintenance expense, 12 to 15 per cent. per annum; and lack of capacity.

## INTERCHANGEABLE SYSTEMS.

**Interchangeable or universal systems** of electrification have received much consideration. It is physically possible, practical, and for economy it is necessary to devise a motor which is interchangeable on alternating-current and direct-current systems.

Single-phase, series, alternating-current, commutator motors are the nearest approach to this much-desired, interchangeable or universal system, since they may be used on 660 to 1500 volts direct-current circuits by placing 2 or 4 single-phase commutator motors in series; on 3,000 to 12,000 volts, by the use of a step-down transformer on the car or locomotive; on a single-phase contactor of a three-phase line; and on both 15 and 25 cycles, if the latter be necessary.

The ultimate interchangeable system will probably embrace:

1. A single contact line, because of the importance of simplicity in railroad switching yards.

2. Voltages between 6000 and 12,000 volts, in order to transfer large blocks of power with a minimum contact line loss and with a low first cost of equipment, and catenary construction for safety in operation.

3. An alternating-current, single-phase commutator motor, which is interchangeable on direct- and alternating-current circuits.

A commutatorless, single-phase induction motor may be designed for practical railroad service. Experiments in 1911 so indicate.

The rectifier may be developed for heavy service.

Allgemeine Elektricitats Gesellschaft manufacture single-phase motors of the repulsion type, which cannot be used on direct-current circuits, and these have been successful in England and Germany.

## RELATIVE ADVANTAGES OF SYSTEMS.

### Summary of Advantages and Disadvantages of the Principal Electric Systems Used for Electric Railway Trains.

The systems compared, in short form, are the direct-current 600–1200-volt; three-phase 15–25-cycle, 3000–6000-volt; and single-phase 15–25 cycle, 6000–11,000-volt.

**Generating equipment,** so far as the prime mover is concerned, is not greatly affected by the electric system.

Direct-current generators are relatively expensive, but they are seldom used for heavy railroad work.

Alternating-current generators are cheaper, since they can be built in larger sizes and for much higher speeds than direct-current commutator machines. Economy of insulation generally required the use of Y-connected alternators, with an e. m. f. of about 11,000 volts.

Generators for single-phase systems may be either single-phase or three-phase. The former, altho more common, are more expensive, since one leg or one-third of the windings is not utilized. The higher cost is offset, however, by lower cost of switchboards.

"It is not much more expensive to use three-phase generators for single-phase distribution, as the new type of dampened field cuts down the rising voltage on the idle phase, making it possible to use three-phase for commercial requirements." Murray, A. I. E. E., Nov. 12, 1909.

**Three-phase generators for single-phase systems** are used in the following four ways:

Neutral points of the three-phase generators are connected to the track, and the 3 phases or legs are connected to the 3 sections or divisions of the trolley contact line. (Rotterdam-Hague-Scheveningen.)

Two legs of the three legs of a Y-connected generator are used for

the electric railway; but the three legs are available for transmission lines to transformer substation, etc. This makes an unbalanced system.

Three-phase two-phase transformation can be used.

Two-phase generators may be used, with one leg of each connected to the track, and each leg connected to insulated sections of the line.

**Power transmission** is not practical with direct current for heavy traffic over distances greater than about 5 miles.

The limitation is in high-voltage commutation, but if this limitation did not exist the minimum pressure to be adopted for ordinary railroad-train service would be 6000 volts.

"The idea of transmitting large blocks of power by means of direct current is a forced idea," as stated by *Behrend.*

Direct-current power must be generated as three-phase, high-potential, alternating current, and transmitted to substations where it is transformed and converted to direct current. About 50 per cent. of the energy generated is distributed to the motor. Single-phase, alternating current distribution losses run from 5 to 15 per cent., where three-phase distribution losses run from 10 to 20 per cent., generally speaking.

The practicability of an electric power system depends upon its ability to transmit, collect, and utilize large blocks of power in an efficient manner. The transmission and distribution of the energy outweigh all other electrical items in electric traction for heavy individual train loads widely scattered on a railway division.

Economy of copper is higher for equal weight of overhead copper with single-phase distribution than with polyphase arrangements. *Murray,* A. I. E. E., Jan., 1908. See Transmission and Contact Lines.

**Motor control losses** in direct-current and three-phase motors during acceleration are large. The efficiency of control of single-phase motors is high, as will be detailed later.

**Motor efficiency** when compared shows that the losses in large direct-current motors used on motor-car trucks are about 12 per cent., and for single-phase motors are 14 per cent.; and that the losses in motors used on large locomotives are 8 per cent. for direct current and three-phase motors and 10 per cent. for single-phase motors. Much depends upon the speed, design, and service.

**Weight** of the single-phase motor is the heaviest because the magnetic heating and commutator losses are the largest; but the motor weight is a small part of the total train weight. See chapter on Railway Motors.

### SUMMARY.

**Principal advantages of the direct-current system:**

Direct-current motors are standard, well-tried, have good operating characteristics, and may be used on 600- and 1200-volt circuits.

Danger is not involved with the low voltages used.

Storage batteries may be used directly to smooth out the load.

Transformers are grouped in rotary-converter substations, not on the moving motor car and electric locomotive.

**Disadvantages of the direct-current system:**

Voltage of line is low, and this causes high transmission, conversion and contact line losses.

Substation and transformer equipment cost is high.

Operation and maintenance of substations are expensive.

Electrolysis of underground structures occurs.

Efficiency of energy transmitted to tra ns is generally the lowest.

Regeneration of energy is not practicable.

**Principal advantages of the three-phase system:**

Commutators are not used on motors.

Efficiency of the motor is the highest.

Constant speed may be used for some service.

Regeneration of energy is most practicable.

**Principal disadvantages of the three-phase system:**

Two overhead trolleys involve danger, particularly around switching yards and for high-speed service. Common overhead catenary construction parallel to the two trolley wires is expensive.

Low contact-line voltages are used. In the three European railroad installations, 3000 volts are used; and in America, on Great Northern Railway, 6000 volts are used. Substations must be frequent, because of the low voltages used on the trolley line.

Motor characteristics are not satisfactory in regard to variable speed, efficiency during acceleration, drawbar pull with reduced voltages, and load factor of motor and generator in constant speed service.

**Principal advantages of the single-phase system:**

Transmission and contact line losses are a minimum.

Transformer and substation expenditures are reduced.

Transformation facilities are perfect.

One trolley wire is used. Simplicity governs the weakest element of the system—the one element which cannot well be duplicate. Simplicity and safety are gained at switching yards and terminals.

Energy required from the power plant is the lowest.

High efficiency is obtained during train acceleration periods, and the motor potential can be varied without rheostatic losses.

Variable speed is obtained from motors. The speed is varied by changing the relation of the secondary and primary taps at the transformer.

Drawbar pull of motors depends *directly* upon the voltage; if the line

voltage is low, the motor voltage may be raised by changes at the step-down transformer.

Transformer substation load factor is very high, because each substation (and often the generating station) reaches out and furnishes power to the diversified load of heavy individual train units, which are widely scattered. (The substation does not carry two 1000-h. p. trains in a 10-mile division, but twenty 1,000-h. p. trains in a 50-mile division. The load is diversified and becomes uniform. The load factors of the transmission line, transformers, and contact line are thus relatively high and the cost per train-mile, ton-mile, or passenger-mile is relatively low. This advantage is of great economic value in railroading.

**Disadvantages of the single-phase system:**

Equipment cost for all short roads is higher.

Maintenance cost of motors is higher.

"Reduced output of both generator and motors; the reduced efficiency; the impaired regulation; the increased heating and less stability of the single-phase motor and generator, and the increased cost resulting from the greater amount of material required." Behrend, 1906.

The single-phase system was first installed for train haulage in 1907.

## COST OF COMPLETE EQUIPMENT.

The cost of the complete equipment can only be stated in general terms. The cost varies for any given train service. Heavy trains and infrequent service always favor the alternating-current systems; while light trains and frequent local service always favor the direct-current system. Multiple-unit operation, distance between stops, and length of road affect the cost of electrical equipment to a great extent.

**Cost of the direct-current system** is extremely high for electric train service because of the greater investment in secondary feeders, substations, transformers, converters, and switchboards. If, however, these could be reduced by the use of a mercury gas rectifier, the situation would be bettered.

**Cost of the three-phase system** is low for light railway work. In Italy where 3000 volts are used, a catenary cable does not support the two trolleys at frequent intervals, as with the single-phase system. For heavy, high-speed railroad work, the cost of equipment with 3000 or 6000 volts is high, because numerous substations are necessary, and catenary construction parallel to the two trolley wires is necessary.

**Cost of the single-phase system** for heavy work is relatively low because of the use of high voltages and the simplicity in construction. In most cases, the absence of line transformers much more than offsets

the higher cost of motors used on motor cars and locomotives. The peak load at the substation is relatively low because the high-voltage distribution from each substation reaches many trains to equalize the load and this decreases the investment for the average output or work.

Cost of equipment is detailed in "Procedure in Railroad Electrification."

## OPERATION AND MAINTENANCE.

There is a reasonable difference of opinion on this subject. Care should be taken to avoid the comparison of data on maintenance of interurban and terminal railways which use 600 and 1200 volts with railroad trains which require higher voltages. They are not comparable. Further, the depreciation of the first alternating-current roads, so recently installed, was larger than it will be in the future.

Direct-current systems are the most expensive to operate, until the interest and depreciation charges become a small part of the operating expense, as in the case of rapid transit service, where the greater part of the investment is in multiple-unit car equipment.

Three-phase operating and maintenance costs may or may not be higher than others. The motors are simple, and the overhead construction is not much more expensive to maintain, but the cost of power will be higher for constant-speed service.

Single-phase maintenance cost, at the present state of the development, is somewhat higher than that for the direct-current, but eventually there will be little difference. Heavy railroad transmission losses will be lower than with other systems, probably from 15 to 20 per cent. lower. The absence of converter substation maintenance is an important matter. In many cases transformer substations will be unnecessary. The combined savings will make the cost of maintenance and operation of the single-phase system 4 to 8 per cent. lower than the direct-current system and probably lower than the three-phase system.

**Indianapolis & Cincinnati Traction Company,** with two divisions from Indianapolis, one to Connersville, 58 miles, and one to Greensburg, 50 miles, and a total mileage of 116, has used the single-phase electric power system since December, 1904. Fifty-ton, 55-foot cars with four 100-h.p. motors are used. Unfortunately, it is compelled to use direct current at terminals, thus requiring a double-control equipment.

In the operation of the power plant "the alternating-current system saves under present conditions about $16,000 or 23 per cent. per annum in operating expenses over what would be the cost of the same operation with direct current." A. D. Lundy, Consulting Engineer, 1907.

**H. M. Hobart** discussed this subject before the British Institution of

Mechanical Engineers in July, 1910, and stated as the result of his calculations, based on what purported to be accurate data, "that the cost of current plus the interest, on the investment in rolling stock, was 6 cents per train-mile higher for single-phase than for direct current in moderate service. The advantages of direct current over single-phase current were more apparent the higher the schedule speed and the shorter the distance between stops."

**J. Dalziel,** of the Midland Railway, in the same discussion stated: "Single-phase in suburban work must have very serious disadvantages to warrant its being discarded when its many advantages for main-line operation are admitted. Much of the trouble with single-phase apparatus was due to the complication involved by attempting to operate single-phase motors on direct-current sections. With regard to efficiency, comparative figures proved that the single-phase motors on the Midland Railway consumed 20 per cent. less current than direct-current motors on the Liverpool-Southport line when running at the same schedule speed."

**Midland Railway of England** equipped its Heysham-Lancaster Branch with single-phase equipment in 1908. The traffic is ordinarily light and consequently expensive to operate by steam; but there is a heavy summer traffic tending to congest the main-line trains. Motor cars are required on a service and schedule very similar to that of the former steam locomotives.

"The single-phase apparatus is equally as capable of working such services (high-speed, frequent stop, suburban-interurban) as direct-current apparatus; the weight of the single-phase train is only a very small percentage greater than that of corresponding direct-current trains." Dalzel and Sayer, to Inst. of Civil Engineers, Nov., 1909.

## CONCLUSIONS AND OPINIONS.

Prussian State, Swedish State, Swiss Federal, and Austria-Hungary Railroad Administration, during the past 5 years have had a commission of noted engineers studying the question of the best system. These commissions have inspected installations, discussed technical and financial data, made long reports, and in each case have finally decided that the 10,000-volt, 15-cycle, single-phase system is best suited for traction on main lines, altho direct-current and the three-phase system have been found applicable under certain conditions. Attention has been called to the fact that the single-phase system complied with the desire for unity of systems in simplifying international communication.

**Italian State Railway** favors the three-phase system. The chief engineer of the electrical department, Mr. Verola, stated in 1909:

"The decision to use the three-phase system is not final and absolute for our administration, but the latter considers it preferable as a beginning for the lines at present under electrification. The possibility of using single-phase systems in other cases, which may better lend themselves to it, is thereby not excluded. In the case of the three lines (Pontedecimo Busalla, Bardonecchia Modane and Savona-Ceva),

the service is extremely heavy, trains of 440 tons and over having to be hauled up on long grades of 2.5 to 3.5 per cent. at a speed of 45 km. per hour. With the three-phase system it is possible to comply with these conditions by using two 67-ton, 2000-h. p. locomotives. The three-phase system has the advantage that in running downhill the speed cannot exceed a certain limit, while recuperation of energy is possible. The advantages of wider speed adjustment in running and better efficiency of the single-phase system in starting are not of importance, since the grades are long and fairly uniform, and the distance between stations is great. Other lines will be worked single-phase. One of these is the Turin-Pinerolo-Torre-Pelice, where widely different speeds are necessary, the maximum being 80 km. per hour for 112-ton passenger trains."

**Sprague** stated before the American Institute of Electrical Engineers, November, 1909, what to the writer appears to be an excellent summary:

"It is not deemed wise first to decide upon a system, but rather to ascertain the costs of locomotives (and motor cars) by various systems which could perform a service determined as essential to effective operation, and then to collate all the facts, advantageous and otherwise, affecting capital cost and cost of operation, after which the best system to meet the existing conditions could be determined. We are passing thru that inevitable stage of development and elimination essential to final correct decisions and permanency of results. However critical we sometimes feel as to the inadequacy of any system in some particular application, every installation is welcomed which promises to further the effective and economic application of electricity to trunk-line operation."

**Stillwell** was more definite, and his remarks on systems are recommended for consideration:

"Standardize with respect to those things which are essential to interchange of rolling stock, by (1) careful study by a competent commission of the broad problem of railway electrification, (2) selection of that system which present knowledge points to as best adapted for a general solution, and (3) concentration of efforts in perfecting the details of a system selected."

This method is contrasted with selections of systems for a specific problem which ignore the obvious fact that the horizon of the present "zones of electrification" is sure to expand in the near future and that these horizons in many instances are certain to overlap before the expiration of the proper period of amortization of the capital invested in the apparatus selected.

**Four conclusions** on systems are now well established.

The direct-current 600- or 1200-volt rotary-converter substation system can best be used to distribute and collect large amounts of energy for dense, local traffic. It is not an efficient system for ordinary railway train service.

The three-phase system will give good results when low-speed, heavy

train service and regeneration of power on grades are combined. It is not adapted for motor-cars, frequent acceleration, and switching.

The single-phase system combines simplicity, flexibility, economy in power transmission, variable speeds, lowest cost for service with heavy individual freight and passenger trains, and the motors used can be run on sections equipped for three-phase or for direct-current operation.

The best system for train service is not one adapted to individual cases, but one which is adapted to the electrification of complete railroads.

The choice of the electric railway system is an important matter. The details and the application of the systems of railway electrification offered must be carefully compared from all physical and financial standpoints. The decision is of importance because it affects safety, capacity, and interchange of equipment; it commits the railway to better or poorer results in operation. Standards should be adopted soon, which will decrease the excessive cost of changing from steam to electric operation, and in order that the public may obtain the benefits of improved transportation facilities and service.

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## CHAPTER V.

# ELECTRIC RAILWAY MOTORS FOR TRAIN SERVICE.

**Outline.**

**Introduction:**

Historical development, voltages, currents, classification with systems.

**Direct or Continuous Current Motors.**

**Three-Phase Alternating-Current Motors.**

**Single-Phase Alternating-Current Motors.**

**Comparison of Motors.**

**Rating of Motors:**

One-hour and continuous ratings, comparisons based on ratings, ventilation of motors, ratings of motors with forced draft, selection of requisite capacity.

**Mechanical and Electrical Data:**

Names and ratings, weights, speeds, dimensions, field and armature data.

**Development of Motor Design:**

1. Magnet frames. 2. Pole pieces. 3. Field coils. 4. Air gap. 5. Armature core. 6. Armature winding. 7. Commutator. 8. Brushes. 9. Armature speed. 10. Bearings. 11. Gearing. 12. Axles. 13. Suspension.

**Speed-Torque Characteristics of Motors:**

Direct- and alternating-current motors; effect of voltage, gearing, drivers.

**Choice of Cycles for Motors, 15 Versus 25.**

**Control of Motors.**

**Literature.**

## CHAPTER V.

# ELECTRIC RAILWAY MOTORS FOR TRAIN SERVICE.

### INTRODUCTION.

A study of electric railway motors embraces types, rating, mechanical and electrical design, running characteristics, and control. Commercial considerations demand capacity, reliability, and low maintenance, for economy in transportation.

The electric motor is but one link in the electric railway; yet it is of first importance. The essential contributing items are ample and economical prime movers, generation at a suitable voltage, cycle, and phase, and a simple and efficient method by which large blocks of energy may be transmitted and transformed. The motor receives the electric power, and simply translates it into the requisite drawbar pull and speed.

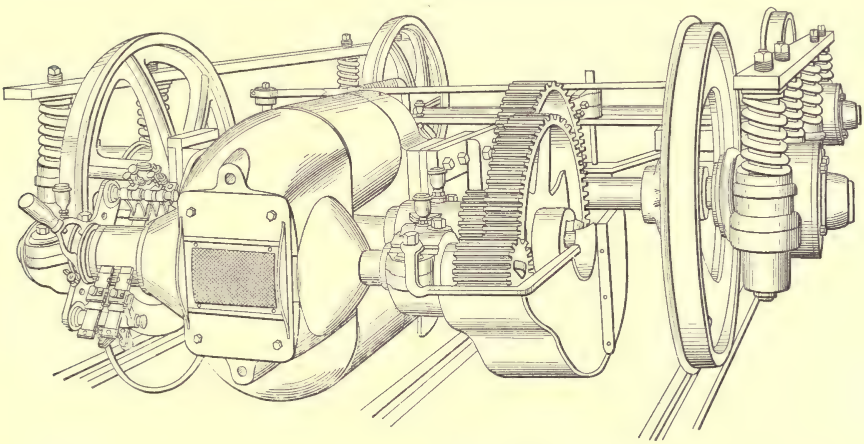


FIG. 27.—STANDARD TRUCK AND MOTOR. BENTLEY-KNIGHT, 1885.
Motor suspension on axle bearings and on a truck crossbar—nose suspension.
Double reduction gears.

**Historically** the first general observation made regarding motors for use on passenger and freight cars is that, about 1890, one motor per truck was mounted on the first double-truck electric cars. About 1898, electric motor cars had become heavier, rapid acceleration and high speeds were used, and coaches were hauled; and the service then required the use of "4-motor equipments." When electric trains are operated in place of single cars, the air resistance and also the rail friction per ton on the private right-of-way are reduced, and two motors per car generally

furnish sufficient capacity. A study of the statistical tables, in "Motor-car Trains," shows exceptions to this rule, particularly where heavy motor cars are used to haul heavy coaches.

Improvements in direct-current motors since 1900 have been few. They include commutating poles and slotting of mica between commutator bars. Three-phase motors were well developed prior to 1902, since which time few changes have been made. Single-phase railway motors have been developed since 1904; they have been rapidly improved, and are well perfected. The commutator troubles on all motors now sold are a minimum, maintenance expense has become a small item, and the depreciation rate is remarkably low.

**Voltages** for direct-current motors were 75 volts as used in 1883 by Field and Edison; 125 volts used in 1884 by Daft with his compound-wound 8-h. p. motor on the Baltimore Union Passenger Railway; and 450 volts used in 1888 by Sprague for two 7-h.p. motors per car at Richmond, Va. The standard voltage for direct-current street railway motors is now 550. Voltages of 600 to 660 volts are used for heavy railway-train service and voltages of 1200 volts with two 600-volt motors connected in series are used by 14 interurban American railways.

Three-phase motors in Europe since 1902 have used 3000 volts on the trolley and on the motors. This limit will not be greatly increased because of the difficulty of insulating motor windings; and because complicated terminal and switching yards with two overhead trolleys involve danger. In America, the Cascade Tunnel of the Great Northern Railway uses three-phase, 6000-volt contact lines, but the controllers and motors use 500 volts.

Series-alternating motors use 250 to 350 volts, and repulsion types use from 250 to 800 volts, or even higher on field windings. The high voltage on the contact line, 3000, 6000, or 11,000 volts, is reduced by transformers on the car or locomotive.

The cycles used on American alternating-current railways are 25, while both 15 and 25 cycles are used in Europe, as previously detailed.

**Classification** of railway motors for electric trains is usually made with reference to the several electric systems. Equipment generally includes prime movers, three-phase generators, transformers to raise the generator voltage, if it is necessary for the power transmission, transformers to reduce the voltage at substations to either 3000, 6000, or 11,000 volts for the three-phase or single-phase trolley contact lines, or to about 410 volts for rotary converters which change the energy to direct current, ordinarily at 660 volts, for the contact line. With an interchangeable single-phase motor, a railway may use direct current for short-distance, rapid-transit, or terminal service from a third-rail contact; or single-phase current for infrequent, heavy, and concentrated

long-distance freight and passenger traffic from one high-voltage trolley of a single-phase or three-phase line.

### DIRECT-CURRENT MOTORS.

Direct-current, 600-volt motors are well established. These motors are series wound, have commutating poles, and are enclosed in a steel frame.

The potential between the contact line and the track rail, 550 to 660 volts, is used by motors on about 95 per cent. of the 36,000 miles of American electric railways. The potential is 1200 volts on about 550 miles of American interurban railways, and, while the motors are insulated for 1200 volts, they run two in series on the 1200-volt line, except in the case of 1200-volt, 75-h. p., G.E.-205 motors used by the Central California Traction Company, in which the number of commutator bars is approximately double, the creepage distances on the commutator and brush holders is double that of standard 600-volt motors, and the field is wound with double insulation on the wire.

The 1200 volts are used outside of large cities and 600 volts within the city limits. The 1200-volt motor is now advocated for heavier work, in competition with the alternating-current motor.

**Series motors** of both direct-current and alternating-current types have been quite universally adopted, because series motors have great magnetic pull, or tractive effort, for starting trains or for running up grades. The tractive effort of the series motor varies approximately inversely as the speed, and thus the load on the motor and on the line is somewhat more uniform than would be the case if the tractive effort and speed were each maintained. Power is proportional to the product of the tractive effort and the speed.

**Advantages of direct-current series motors:**

Speed-torque characteristics enable them to automatically protect themselves from electric heating, which varies as the square of the current input. Since the speed is not maintained with the tractive effort, the motor is of smaller size, weight, and cost, for a given or average amount of work.

Safety is obtained with the low trolley voltage used.

They are standardized and have been adopted for city service.

Two 600-volt motors may be used in series on 1200-volt lines.

Compared with single-phase motors, commutation is better, efficiency is higher, armatures are smaller, speed is lower, weight is less, cost is less, and maintenance expense is lower.

**Disadvantages of direct-current series motors:**

Cost of the complete system is highest because of the trans-

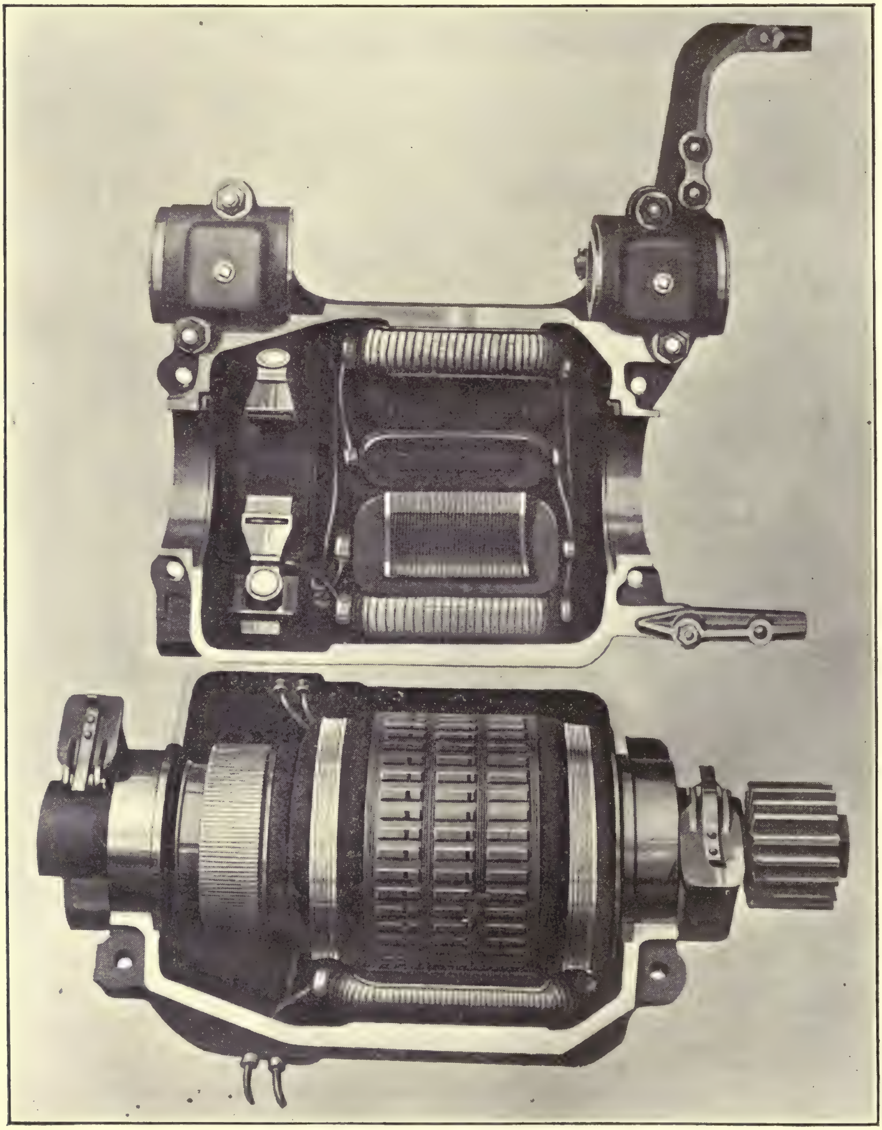


FIG. 28.—ALLIS-CHALMERS 501 ELECTRIC RAILWAY MOTOR.
Fifty-h. p. on 600 volts; 42-h. p. on 500 volts, direct current. Interpoles are shown in the open field frame.

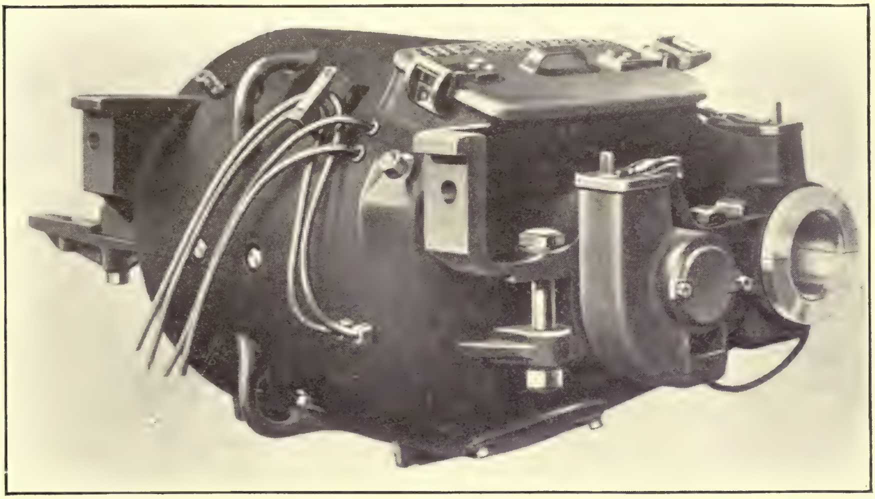


FIG. 29.—ALLIS CHALMERS 501 ELECTRIC RAILWAY MOTOR.
View is from suspension side, and with closed field frame.

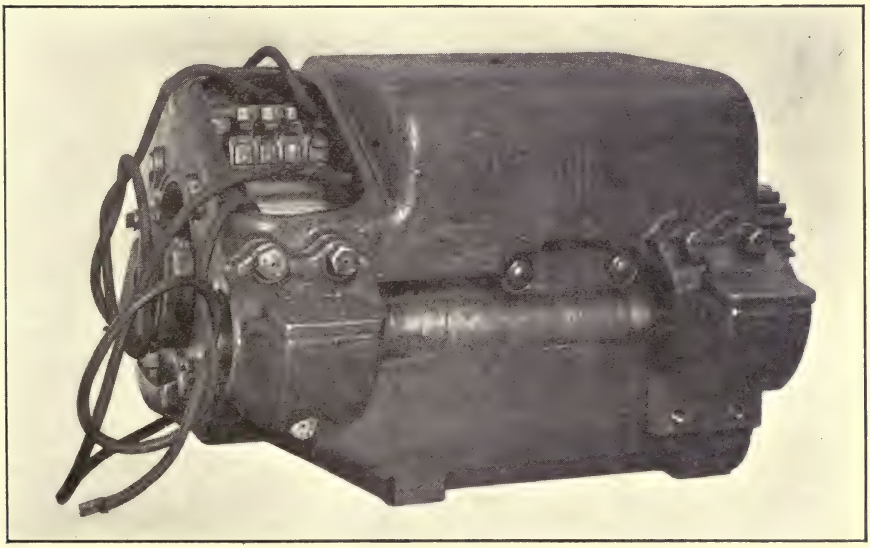


FIG. 30.—BUFFALO AND LOCKPORT RAILWAY MOTOR FOR 1898 LOCOMOTIVE.
Cover removed. Capacity 160 horse power.

formations, 600-volt converter substations, extra labor required, and expensive local distributing feeders for railroad-train service.

Insulation of 1200 volts in motors and controllers increases the size, weight, and cost. Flashing from commutator to brush holders and to nearby frames, increases the operating expense and liability of trouble.

### THREE-PHASE MOTORS.

Three-phase motors are now established for a limited use. They are known as constant-speed motors to distinguish them from series or variable-speed motors; yet the speed of three-phase motors can be varied in several ways, as will be detailed under Control of Motors. The acceleration of three-phase motors is at a full rate up to full speed, and this characteristic calls for high-power peaks on the motor, the line, and the power plant.

The speed of rotation depends upon the frequency of the cycles of the generator, which is practically constant. When the motor is rotating at maximum speed, it is at synchronous speed. The speed slows down 2 to 5 per cent. on full load. When resistance is inserted in the rotor circuit of three-phase motors, there is a negative "slip," or difference between the rate of rotation of the rotor and of the power generator. When the rotor is forced above speed, in down-grade running, there is a positive "slip," and energy can be regenerated and returned to the source of supply.

Three-phase motors are not used for frequent stops or rapid transit service, or for switching, because either the efficiency or the drawbar pull is poor during the acceleration period. Their use is limited, fundamentally, to long-distance running. For installations on railroads, see "Electric Systems," Chapter IV.

The stator of the motor consists of a steel casting which holds a laminated magnetic ring. Electrically, the stator is the primary of a transformer, while the rotor or armature is the secondary. Alternating three-phase current is supplied from the power plant to the primary winding, and three-phase current is induced in the rotor or secondary. The interaction produces the torque and drawbar pull. The rotor may have collector rings, in order that resistance may be inserted to limit the induced current, and to increase the torque; or the rotor may be of *high* resistance but of the short-circuited, "squirrel-cage" type.

Three-phase motors have no commutators, and would be ideal for railroad work if they could be used with a single-phase high-voltage contact line, but when so operated they lose their best characteristics.

L. C. de Muralt, publisher of a monthly leaflet (Electric Trunk Line Age) which advocates the three-phase system, announced in May, 1909, that there had been designed and operated in practical service, at the University of Michigan, a good three-phase motor for electric railway purposes which ran successfully on single-phase circuits. If this were true, an important development might be expected, because it would place the three-phase induction motor on a different basis.

**A three-phase motor, operating single-phase,** with two of its terminals connected to the single-phase mains, runs as a single-phase induction motor. The third terminal must be connected to a phase-displacing device to get the necessary cross magnetization for producing torque by its action upon the induced secondary energy currents. The torque of the three-phase induction motor on a single-phase circuit is zero in starting, or the motor will not start. Resistance may be inserted in the secondary, as in three-phase motors, to increase the torque. When well above half-speed, torque will be delivered until the motor is overloaded, after which it will die down.

McAllister: "Alternating-current Motors," 3rd Ed., p. 58.
Garlecon: Polyphase Motors run Single-phase, Electric Journal, Aug., 1905.

**Advantages of three-phase motors:**

1. Electrical efficiency of three-phase motors is high. An efficiency of .91 is obtained, where .90 is common with direct-current, and .87 with single-phase motors. The energy lost—9, 10, 13 per cent.—must be radiated. The reasons for the higher efficiency are:

a. Laminated fields and cores which are used are not saturated, air gaps are very short, and the iron losses are low.

b. Commutator losses are absent.

c. Maximum efficiency of radiation is possible.

Losses in three-phase motors are produced chiefly in the distributed stationary windings in the shell of the motor, and the heat reaches the outside or radiating surface easily and quickly, particularly so with overloads. Losses in direct-current and single-phase alternating-current motors are chiefly in the rotating element, and the heat must pass thru the field or external structure to reach the external radiating surface. The windings of three-phase and single-phase motors are more evenly distributed than the windings of direct-current motors.

2. Energy required for the three-phase system is low; but the motor losses are generally overbalanced by the high line losses, making the power required about the same as for the single-phase system, as is shown by an example which follows.

POWER REQUIRED WITH DIFFERENT ELECTRIC SYSTEMS.

| Motor or system. | 3-phase. | 1-phase. | Direct. |
|---|---|---|---|
| Weight of cars in train, in tons | 1000 | 1000 | 1000 |
| Weight of locomotive, in tons | 96 to 93 | 131 | 100 |
| Total weight of train, in tons | 1093 | 1131 | 1100 |
| Speed of train, in m.p.h | 37.5 | 37.5 | 37.5 |
| Efficiency of electric motors, per cent | 91 | 87 | 90 |
| Power required from contact line | 1200 | 1300 | 1222 |
| Voltage on contact line | 3500 | 11000 | 1200 |
| Efficiency of contact line, per cent | 85 to 88 | 95 | 85 |
| Efficiency of transformers, per cent | 96 | 96 | 86 |
| Horse power required from power plant | 1421 | 1427 | 1672 |
| Relative power required per train | 100 | 100 | 117 |

The example is fair for a common 1000-ton freight train at 37.5 m. p. h., or a 500-ton passenger train at 65 m. p. h., the train resistance being 10 pounds per ton. The constants will vary with the amount of money expended for transformers and feeders. On short routes and light trains, the showing of the 1200-volt direct-current system is improved.

3. Energy can be restored to the electric line during braking.

4. Safety is gained by means of electric braking during regeneration of energy. Wrecks which are now caused by excessive wear of brake shoes, breakage of brake rigging, and overheated wheel tires in heavy trains on the long down-grades, can be prevented.

5. Weight efficiency of three-phase motors themselves is high. The lighter motor reduces the weight of supporting frames, the dead load hauled, the cost of motors, and the cost of track maintenance. Some three-phase locomotives for freight haulage require ballast.

6. Maximum torque may be obtained, from the start to the full speed, which is a physical advantage in train acceleration. This is offset by the greater cost of power, and the greater losses in control and in the motors, during acceleration.

**Objectionable characteristics of three-phase motors:**

1. One-speed characteristics are a limitation. For some situations both unification of speed and a fixed maximum speed may be advantageous, but not under present methods in railroading. A distinct loss is evident when the "velocity head" cannot be utilized. The speed of three-phase motors cannot be varied economically. See Motor Control.

2. Heavy loads are imposed by the constant-speed motor characteristics, and these increase the cost, the size, and the weight of the motor

per average h. p. developed. The power required for constant speed on the up-grade increases rapidly and this requires a relatively high 1- hour or continuous capacity in three-phase motors. See diagram below.

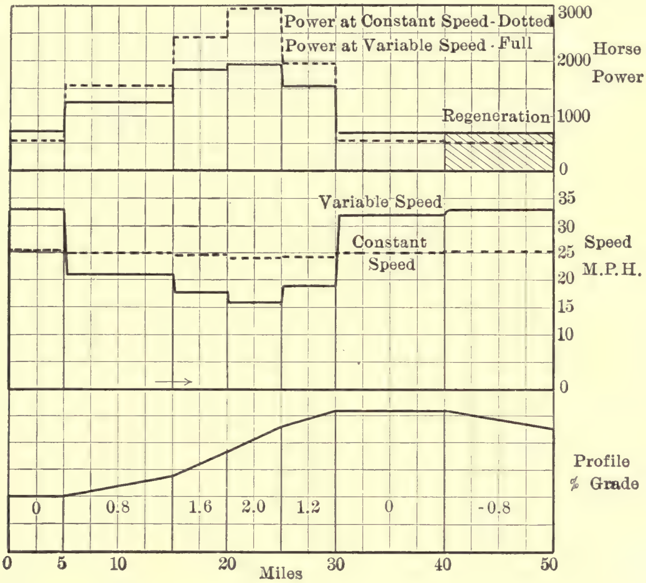



FIG. 31.—DIAGRAM OF HORSE POWER FROM MOTORS ON CONSTANT AND ON VARIABLE SPEED WHEN WORKING ON DIFFERENT GRADES.

The total train weights are equal, 1000 tons. The average speed, 25 m. p. h., and the running time are the same. The average horse power of the locomotive motors must therefore be equal. The comparison noted in the diagram is fair. Constant-speed locomotive motors are heavier and of greater rated capacity than variable-speed locomotive motors.

3. Air gaps which are used, 1/8 to 1/16 inch, require long bearings or frequent renewals, in all heavy work. With the gears or cranks, and often collector rings on the shaft, sufficient length for bearings is not available. A short air gap clogs with dust and prevents ventilation.

4. Two overhead wires are required with a three-phase motor. This increases the line cost, complication, maintenance expense, and danger.

5. In design, a 15-cycle, 2-, 4-, 6- or 8-pole, three-phase motor runs at a speed of 900, 450, 300 or 225 r. p. m., whereas a series, single-phase, or direct-current motor can run at higher variable speeds, for service in a rolling country, and may thus be lighter and cheaper.

Mr. N. W. Storer, in making calculations for motors to fulfil the conditions of the New Haven Railroad service, found that to accelerate the loads, and to give the maximum speed of 65 m. p. h. now provided by the 1000-h. p., single-phase locomotives, a 1500-h. p. three-phase locomotive would have been required.

6. Efficiency of three-phase motors during the starting period is low, and this is a drawback in railroading where trains are constantly starting and stopping, and where the motors are working at their full speed and efficiency for a small fraction of the total time. The rheostatic losses in the rotor circuits are such that the average efficiency of the power from start to full speed is below 50 per cent. in practice.

Efficiency is reduced at loaded running speeds by the stray fields from primary and secondary circuits, and also by the iron loss in the secondary, in which the frequency of alternations is about 6 times the frequency of the supply. The iron loss is proportional to the 1.5th power of the maximum induction and to the frequency. Considering both the primary and secondary, the iron loss of the motor when loaded is three times its iron loss when running light. Wilson and Lydall, II, 22.

7. Torque or drawbar pull of three-phase motors varies as the *square* of the voltage impressed upon the motor, while the torque of series motors is quite independent of the voltage impressed upon the motor.

The contact line voltage, 3000 to 6000 volts, which must be used with the three-phase system is relatively low, and the line must be designed with many substations and sufficient copper to prevent low voltage. Three-phase induction motors on low line voltage fall out, or die down, or do not start when overloads occur in freight service.

A 20 per cent. line loss results in a 36 per cent. loss in drawbar pull. The maximum voltage is necessary for efficient and ample drawbar pull, and a lower voltage is desirable for running, or exactly the opposite of what is furnished under normal conditions.

Torque or turning effort of three-phase induction motors requires a given amount of power to develop it, regardless of the speed at which the motor is running. At full speed most of the electrical power applied to the motor appears as mechanical output; but, at fractional speeds, the same electrical power applied delivers mechanical power in proportion to the speed, the balance being wasted in heat.

The starting torque of three-phase motors, with starting resistance in the rotor, for a given current, is the same as the running torque; while the starting torque of a short-circuited or squirrel-cage rotor is far less than the running torque for the same current.

8. Motor-car train operation involves difficulties because:

Diameter of three-phase motors is large, and thus the wheel diameter and height of the car body are increased.

Length of axle is not sufficient for twin motors, used with two-speed cascade operation.

The load on each motor varies with the diameter of its set of drivers. About 4 per cent. difference, or 1.6 inches for 42-inch drivers, makes 100 per cent. variation in work done by a motor. Danger from overloads of

the individual motors in the train is thus increased as the drivers wear, or are changed; not so with series-wound alternating- and direct-current motors.

## SINGLE-PHASE MOTORS.

Single-phase alternating-current motors for the haulage of trains are a recent development. The first installation for railroad trains was made in 1907. See "Electric Systems."

Single-phase motors are best adapted for railroads, where the amount of power required is large and concentrated in trains, and where the distances are long. The largest users of such motors are:

New York, New Haven and Hartford Railroad; Erie Railroad, Rochester Division; Grand Trunk Railway, Port Huron-Sarnia Tunnel; Chicago, Lake Shore & South Bend Railway; Rock Island Southern Railroad; Spokane & Inland Empire Railroad; London, Brighton & South Coast Railway; Swedish State Railway; Southern Railway, France; Rotterdam-Hague-Scheveningen, Holland; Prussian, Bavarian, Baden State Railways; St. Polten-Mariazell Railroad, Austria; Bernese-Alps Railway, Switzerland.

**Types of single-phase motors are two:**

**Series motors,** with a commutator, for use on either single-phase or direct-current circuits, a direct-current motor adapted for alternating-current working. The main current or part of it usually flows thru both the field and the armature.

**Repulsion motors,** with a commutator, for use exclusively on single-phase or one leg of three-phase circuits. This motor is built by General Electric Company in America and by Allgemeine Elektricitats Gesellschaft in Europe. Repulsion motor armature e. m. f. and current are produced by electromagnetic induction, as in the rotor of the three-phase motor. The conductors on the armature form the secondary of the transformer, and the primary is wound on the motor fields.

Repulsion motors are used advantageously where the railroad terminal is not handicapped by direct current.

Commutatorless single-phase motors which might reduce the maintenance expense, weight, complication, and valuable space now needed for commutators, may yet be developed for electric traction.

Sub-types of single-phase railway motors are legion.

In the diagram of connections, the field circuits, the compensating circuits, and the armature circuits are shown. The primary and secondary circuits and the various taps at the transformer are not shown.

(A) Series motor, with simplest and poorest connections.

(B) Series motor, with reverse series compensating winding, often called a conductively compensated series motor.

(C) Series motor, of the inductively compensated type; that is, with short-circuited auxiliary field winding.

(D) Series motor, inductively compensated with secondary compensation.

(E) Induction motor, simplest connections (Elihu Thomson). Brushes are given an angular lead and armature is short-circuited.

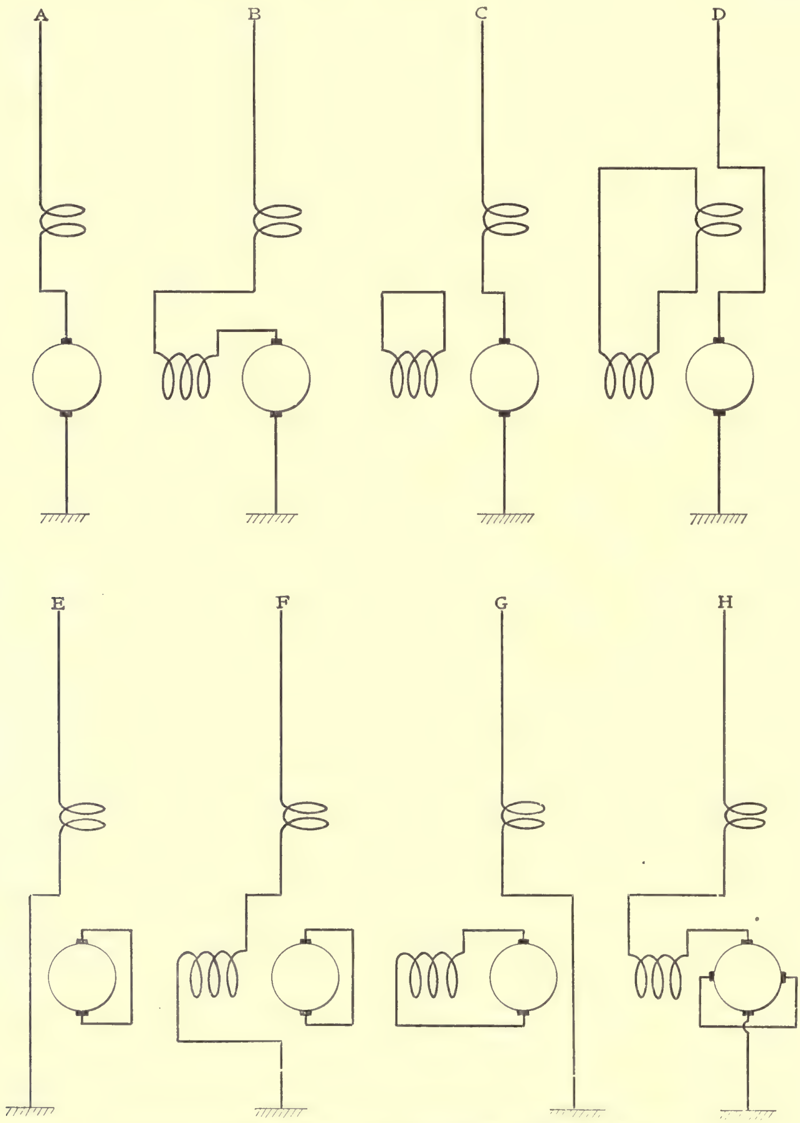



FIG. 32.—SIMPLEST TYPE OF SINGLE-PHASE RAILWAY MOTORS.

(F) Induction motor, plain, with short-circuited armature.

(G) Induction motor, with secondary excitation.

(H) Induction motor, series type.

**References on Connections.**

New Haven direct-current-alternating-current Locomotives, E. R. J., Aug. 24, 1907 p. 280; Murray, A. I. E. E., April, 1911.

Alexanderson motor: A. I. E. E., Jan., 1908; E. W., Jan. 18, 1908, p. 145; as used on N. Y. N. H. & H. motor cars, E. R. J., May 5, 1909, p. 900.

(B) Erie Railroad, S. R. J., Oct. 12, 1907, p. 661.

(C) Rock Island Southern Ry., Electric Journal, Oct., 1910, p. 790.

(H) London, Brighton & South Coast, in Dawson's "Electric Traction for Railways," pp. 139 and 161. Allgemeine Elektricitats Gesell., E. W., July 21, 1910, p. 146.

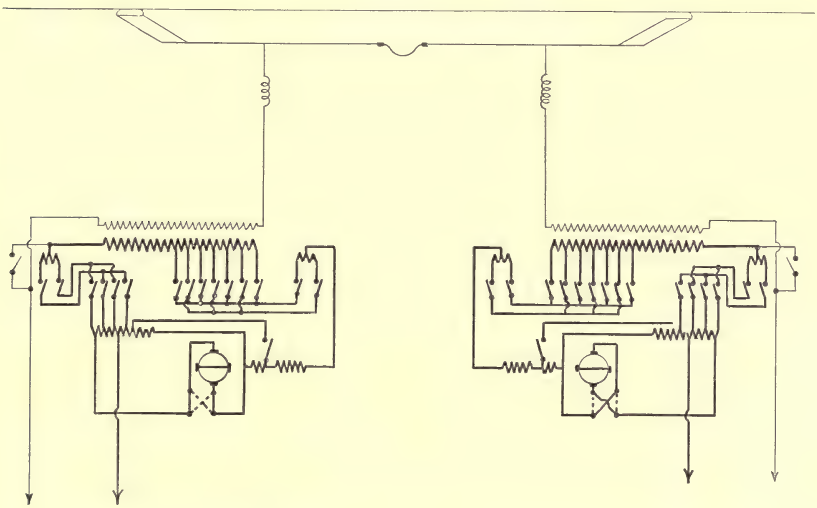


Fig. 33.—Diagram of Connections for Berne-Lotschberg-Simplon Single-phase A. E. G Locomotive Motors.
Transformer voltage 15,000. Motor voltage 420.

## GENERAL CHARACTERISTICS OF ALL SINGLE-PHASE MOTORS.

Laminated magnetic fields are used, the laminated steel ring core being held by an independent steel enclosing case.

Field windings are distributed in slots, in the entire inner circumference of the field core, and there are no salient poles.

Armature windings or coils are made up and connected to the commutator in the same way as in direct-current motors. Resistance leads are placed between the coils and commutator of series motors to reduce the short-circuit currents induced in the coils by the transformer action of the main field, particularly when the motor is starting. This resistance is not always used with repulsion motors.

Sparking exists at the commutator brushes largely because the reversals of current occur at the top of the current wave, which is about 40 per cent. higher than the mean effective value.

Compensation or auxiliary series windings in the slots in the pole

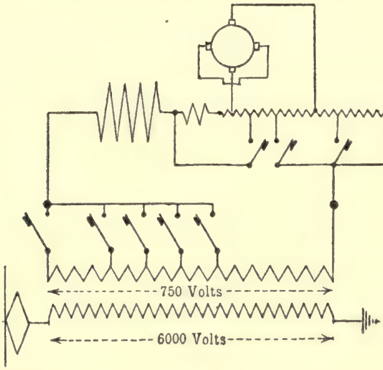
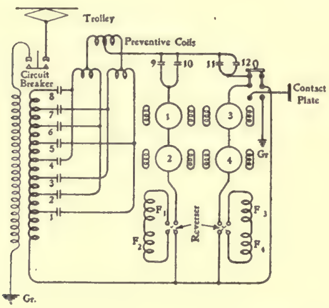



FIG. 34.—DETAILS OF CONNECTIONS FOR ALLGEMEINE ELEKTRICITATS-GESELLSCHAFT SINGLE-PHASE REPULSION-TYPE MOTORS.




Sequence of Switches

| Step | Switches | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | | | | | | | | 9 | 10 | 11 | 12 |
| | 1 | 2 | | | | | | | 9 | 10 | 11 | 12 |
| 2 | 1 | 2 | 3 | | | | | | 9 | 10 | 11 | 12 |
| | 1 | 2 | 3 | 4 | | | | | 9 | 10 | 11 | 12 |
| 3 | | 2 | 3 | 4 | 5 | | | | 9 | 10 | 11 | 12 |
| 4 | | | 3 | 4 | 5 | 6 | | | 9 | 10 | 11 | 12 |
| 5 | | | | 4 | 5 | 6 | 7 | | 9 | 10 | 11 | 12 |
| 6 | | | | | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

FIG. 35.

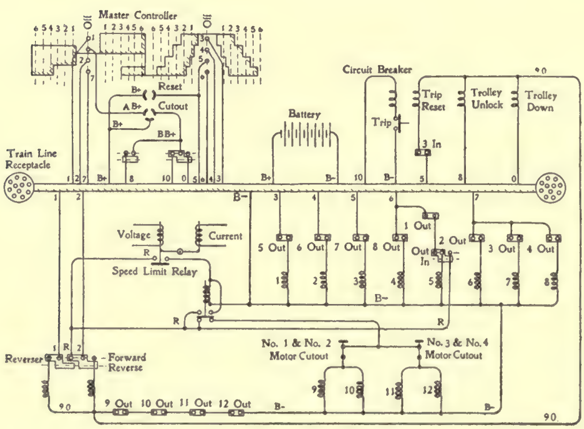



FIG. 36.—DETAILS OF CONNECTIONS FOR WESTINGHOUSE SINGLE-PHASE, SERIES-COMPENSATED TYPE LOCOMOTIVE MOTORS.

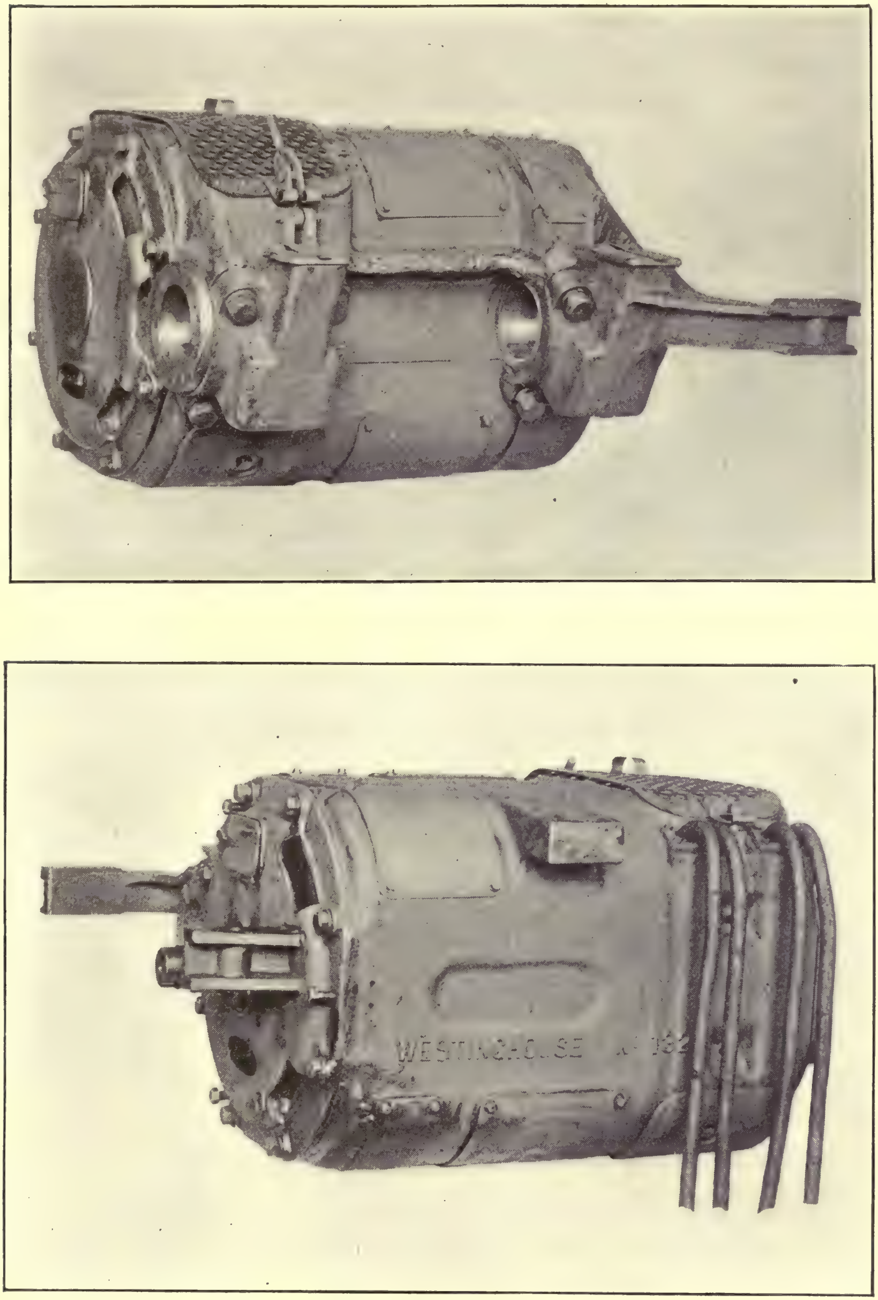


FIG. 37.—VISALIA ELECTRIC LOCOMOTIVE MOTOR.
Single-phase, 15-cycle, 125-h. p., Westinghouse motor. Two views.

faces are required to oppose the inductive elements and thereby maintain the power-factor of the motor.

Air gaps are short and fields are weak, to reduce the self induction. Air gaps are much longer than those on three-phase motors.

Transformers are necessary to reduce the trolley voltage, ordinarily 11,000 volts, to from 250 to 800 for the motor. Much higher voltages could be used for the fields alone.

Potential control is used, and the motor terminals are shifted from tap to tap of the step-down transformer.

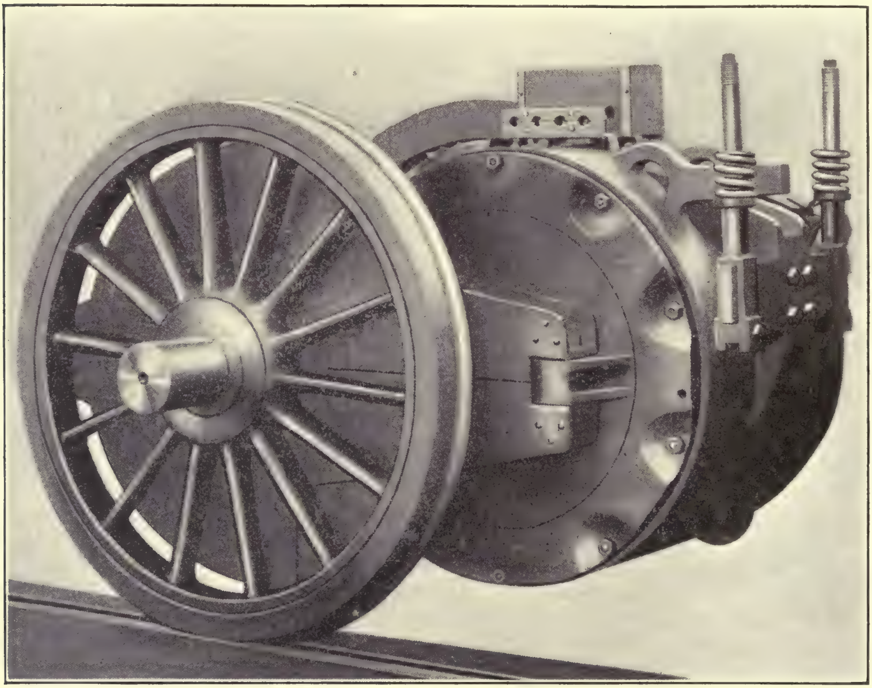


Fig. 38.—Grand Trunk Railway Locomotive Motor.
Single-phase, 25-cycle, 240-h. p., geared, nose and axle mounted. Driver diameter 62 inches.

**Repulsion motors** generally have these added features:

Brushes are placed 180 electrical degrees apart and short-circuited upon themselves. Brushes are given a location about 15 degrees from the line of polarization of the primary magnetism. Two pairs of brushes are often used, placed at 90 degrees from each other, and one pair is short-circuited on itself; and may be varied in position, in motor control.

Open stator slots are used in place of closed slots.

Power factor is higher and may approach unity.

Air gaps are longer than those in series motors.
Voltages used across the motor are higher.
Number of poles is reduced and speed is lower.
Weight and space efficiency are sometimes improved.

## COMMERCIAL SINGLE-PHASE MOTORS.

**Commercial motors** used by single-phase railways are noted:
Compensated-series motors of the Westinghouse Company.
Compensated-repulsion motors used by the General Electric Company

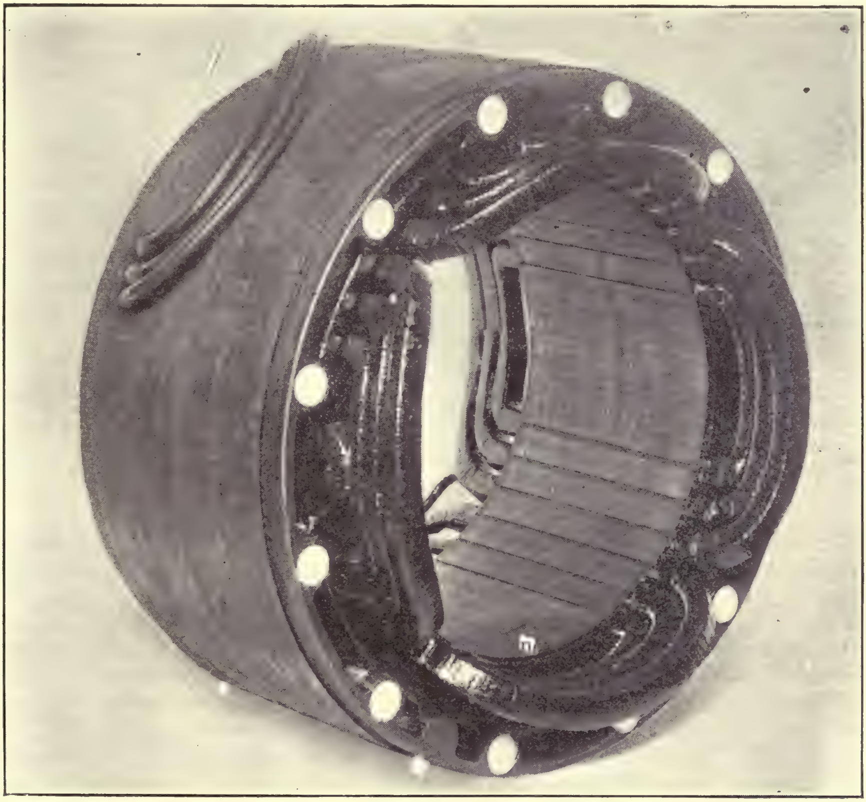


Fig. 39.—Winter-Eichberg Single-phase Railway Motor.
Showing main magnetizing coils and commutating coils in stator.

prior to 1907. The motor has a short-circuited armature and an extra set of brushes for compensation, and to obtain a high power-factor.

Series-repulsion motors of the General Electric Company, the Alexanderson motor of 1907, which embodied many of the features of the repulsion motor and of the compensated-series motor. In presenting

"A Single-phase Railway Motor," to the A. I. E. E., January, 1908, Mr. Alexanderson stated: "In the series-repulsion motor, the problem of commutation has been solved"; and Mr. Steinmetz in comment stated:

"It appears, therefore, that the second and last serious problem of the alternating-current motor which still remained—the problem of commutation—has been solved by the work recorded. The alternating-current, single-phase motor is in practically as good shape as the direct-current motor, and the second period in the development of the alternating-current motor is concluded." A. I. E. E., Jan., 1908, p. 38.

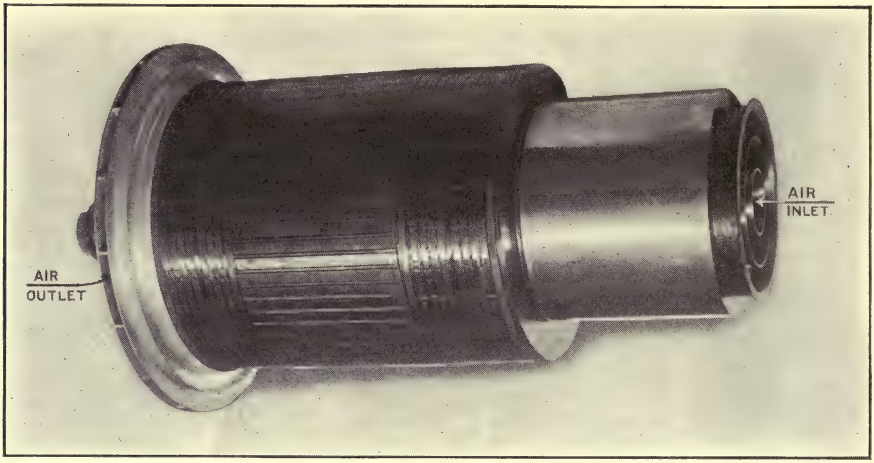



FIG. 40.—WINTER-EICHBERG (A. E. G.) 25-CYCLE, SINGLE-PHASE, 120-H. P RAILWAY MOTOR ARMATURE. Showing ventilating duct, core and commutator.

**Winter-Eichberg Motor,** briefly, has two sets of brushes on the armature, one of which sets is short-circuited on itself, and carries the equivalent of the working current, while the other carries the magnetizing or exciting current which is supplied to the armature winding instead of the field. The arrangement is such as to give about the same effect as a commutating pole or commutating field. When starting, the field flux is decreased and the armature ampere-turns increased. On the Blankanese Ohlsdorf Railway: "Motors have a 1-hour output of 200 h. p. at 500 r. p. m. The continuous rating is 100 h. p.; the weight including gear case, 7260 pounds; the gear ratio, 3.05. The single-phase stator winding has 6 poles. The working winding is in series with an interpole winding, and each of the poles consists of 3 coils. Every second pole has a commutating coil. For low speeds the commutating coils are in series with the working coils. For high speeds the commutating coils receive energy at a certain pressure from taps on the exciter transformer. The air-gap is 3 mm., yet the power factor remains almost unity. The rotor winding is a normal direct-current winding. There are 8 brush holders, 6 of which are short-circuited on themselves and 2 are used for exciter brushes."

**Deri** single-phase motors of Brown, Boveri & Company are also of the repulsion type. The rotor is similar to the armature of a direct-current motor. The brushes short-circuit the armature and are so arranged mechanically that the brush axis may

be set at various angles with the axis of the stator field. Two sets of brushes are used, one being fixed in the polar axis of the stator, and the other so adjustable as to make different angles with the fixed brushes. The movable brushes are not short-circuited on each other, but each is short-circuited on its corresponding fixed brush. If their angular distance is 180 degrees, the armature winding acts as the short-circuited secondary of a transformer and no torque is exerted. As the angular distance between the fixed and movable brush is varied from no degrees to 180 degrees, a torque is exerted; and if the armature is allowed to run, the current decreases and the power factor increases. The effect of shifting the brushes is analogous to changing the impressed voltage on direct-current series motor.

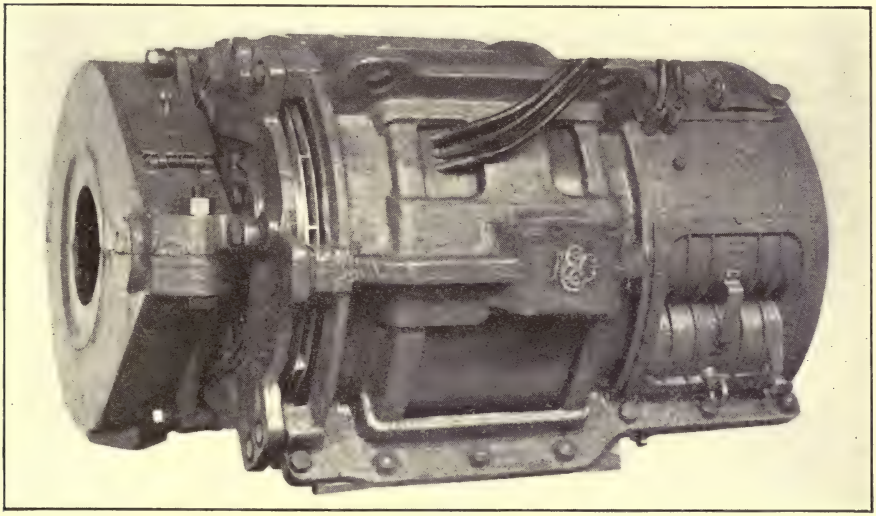


Fig. 41.—Winter-Eichberg (A. E. G.), 25-cycle, Repulsion Type, 750-volts, 120-h. p., Single-phase Railway Motor.
Used on Blankanese-Hamburg-Ohlsdorf and on London, Brighton and South Coast.

The stator of the motor is fed from the line, and even for small motors a pressure of 3000 volts may be used on the field. The rotor is entirely independent of the line and has no connection whatever with the stator circuit. Torque, direction of rotation, and speed of the motor are regulated by means of the movable set of brushes. Variation of speed is attained by changing the potential of the supply current to the field. The windings are simply reduced to two. The commutator is only half as wide as on compensated-series motors of equal capacity, and with the same number of poles.

**References:** Electrotechnischer Anzeiger, Jan. 2, 1910; Dr. Gisbert Kapp to Inst. of Elec. Engineers, Nov. 11, 1909; E. W., July 8, 1911, p. 104.

**Advantages of single-phase commutator motors:**

1. Cost of equipment and of electric systems are reduced.

2. Cost of operation of the electric system is reduced.

3. Potential control is more economical than rheostatic, or concatenation, or series-parallel control; it is of a decidedly superior type; it is

uniform and does not subject the train to jerks, caused by changing the combinations of motors or the poles of motors.

4. An interchangeable series motor can be provided for either alternating- or direct-current circuits, for long distance or for city service or for use on three-phase circuits. (Increase in weight and the complication of the control for interchangeable circuits must be considered.)

5. Power required for single-phase motor trains is usually less than with direct-current motor trains. *Dawson* has shown this with various average speeds from 20 miles per hour to 28 miles per hour. He assumed for the 500-volt direct-current trains a weight of 147.3 tons, and for corresponding 6000-volt alternating-current trains, 162.6 tons. The equipment used in the trains was eight G.E.-66 direct-current motors and eight W.E.-51 single-phase motors. Each train then had 1000-h. p. capacity. The load on each train was 16 tons and the distance 3/4 mile. The energy consumption per train-mile for the alternating-current train was always less than that of the direct-current train when the speed was above the average of 20 miles per hour.

**Disadvantages of single-phase commutator motors:**

1. Heating of motors is greater.
2. Weight per horse power is high.
3. Torque is pulsating and is lower.
4. Power factor is not unity.
5. Cost of motor is higher.
6. Cost of motor maintenance is higher.

**References.**

Parshall and Hobart: "Electric Railway Engineering."
Dawson: "Electric Traction on Railways," Chapters on single-phase motors.
McLaren, in Electric Journal, August, 1907.

Some of these disadvantages are now discussed briefly.

1. **Heating** is greater with single-phase motors than with direct-current motors on account of the following four reasons:

Magnetic losses are larger, because there are well-saturated magnetic circuits in the armature of the motor.

Commutation losses are larger with single-phase than with direct-current motors, because the current is commutated at the peak of the current wave, which is 40 per cent. higher than the average current shown by an ammeter. Commutator difficulties are overcome in several ways:

(a) Commutation coils are used to induce a counter voltage of suitable phase and strength and to destroy the armature reaction.

(b) Resistance or preventive leads are placed between armature windings and commutator bars, to limit the current between any two sets of coils when the carbon brush short-circuits the coils. (Brushes must be set to avoid short-circuiting.)

(c) Low voltages are used across the armature to reduce the voltage per commutator bar.

(d) Diameter or length of the commutator is increased for the proportionately greater current per bar.

Current losses are larger because the power factor is not unity. The I R heat losses in the copper windings are thus greater.

Efficiency is lower than in other motors because of these larger magnetic, commutator, and current losses.

Forced ventilation of alternating-current railway motors has been adopted; and it is so effective that heating is not a limiting feature.

2. **Weight of single-phase motors per h. p. is higher** because heating is greater, and lower voltages and larger commutators must be used. Efficiency is lower and dimensions are larger.

Weight of single-phase motors of 200 to 800 h.p. varies with the ratio of gear reduction and the peripheral speed used in design, but it is clear that the weight, with or without forced draft, is 40 to 85 per cent. heavier than comparable direct-current motors, and this forms a serious handicap.

Midland Railway of England uses single-phase motors which are about one-third heavier than the corresponding direct-current motors; but when the whole train is taken into consideration, the additional weight amounts to from 12 to 3 per cent., depending on the cars per train. This difference would be reduced if the rolling stock were made for thru running. Deely, in London Electrician, July 30, 1909.

3. **Starting torque** of single-phase motors is lower than with direct-current motors. (Starting torque of three-phase motors is much lower than that of direct-current motors, but for entirely different reasons.) Starting torque depends upon the current; therefore, to increase the starting torque it is usual to use a low voltage for the armature, commutator, and motor.

"Drawbar pull per pound of motor weight of the single-phase alternating-current motor must necessarily be lower than that of the direct-current motor, because in the alternating-current motor the magnetic field pulsates between zero and a maximum. The same motor, when energized by direct current, with the same maximum magnetic flux, would give 41 per cent. more output." (Steinmetz.)

Starting torque is ample in existing designs, as shown by the records of the New Haven passenger and freight locomotives, the motors of which are frequently called upon to exert twice their hour rating torque in starting, which is more than is expected of direct-current motors of equal size; and by the Grand Trunk locomotives which start 1000-ton trains on a 2 per cent. grade without taking the slack out of the train. The heavy currents used have in no way affected the preventive leads. The method used by the General Electric and Westinghouse Companies to dampen out the pulsating torque or vibration will be discussed under "Drawbar Pull of Electric Locomotives" in the first part of VII.

Where the vibration is not dampened, a decided handicap exists, particularly on overloads, in small 15-cycle motors. Springs in the pinion or gear seem to be mechanically impractical; but where dampening springs are used, on locomotives and large motor cars, or where the motors are spring mounted, the vibration presents few difficulties.

COMPARISON OF SINGLE-PHASE AND DIRECT CURRENT MOTORS.

Sprague, "Electric Trunk Line Operation," A. I. E. E., May, 1907.

| Items. | Direct current. | Alternating current. |
|---|---|---|
| Magnet frame | Integral | Laminated and less rigid. |
| Field coils | Freely ventilated | Imbedded in field magnet. |
| Strains | Strains of one character | Rapidly variable; alternating. |
| Polar clearance | Large for ample bearings | One-third of direct current. |
| Poles and brushes | Two to four | Four to twelve. |
| Magnetic flux | High saturation and torque | Weak field, low torque. |
| Armature | Moderate sized, slow speed | Large diameter, high speed. |
| Gearing | Low reduction, large pitch | High reduction, weak pitch. |
| Mean torque | Maximum torque of a continuous character. | Half of maximum, and variable without special devices. |
| Armature coils | Direct to commutator | Resistances between coils. |
| Gearing | None, due to low speed | Gearing generally required. |
| Electric braking | Reliable | Not reliable. |
| Capacity | Unity, per pound of weight | One half, for same weight. |
| Continuous rating | 53% of one-hour rating | 35% of one-hour rating. |

**Steinmetz,** referring to the single-phase motor, says:

"A single-phase commutator motor with a good power factor must have few field turns, many armature turns, a weak field with a strong armature. The armature reaction and self induction must be neutralized by a compensated winding; a coil surrounding the armature as close as possible and energized either by the main current in series and in opposite direction to the armature current or closed upon itself and energized by its secondary induced current,—the conductively compensated, and the inductively compensated.

"This means that the alternating-current motor has to be designed with 8 to 12 poles, where the direct-current motor would have 4 to 6 poles. It means that the alternating-current motor has to be supplied with a very large commutator to receive the current at 200 volts, while the direct-current motor commutates much smaller currents at 600 volts. So weight and size must be sacrificed to get reasonable commutation." A. I. E. E., Jan., 1908, p. 36.

**Steinmetz,** referring to single-phase motors in a discussion on the New Haven electrification to A. I. E. E., Dec. 11, 1908, p. 1683, states:

"It is especially gratifying to see the statements which have been made by unbiased engineers, based upon theoretical considerations, have now been verified by practical experience, and that heavy railroad work can be handled by single-phase alternating-current motors, tho obviously not with the same high drawbar pull per ton of locomotive weight, and possibly, at least for the present, not with quite the same reliability of service.

"This I believe establishes the single-phase alternating-current motor as one of the pieces of apparatus by which the future electrification of our country's railway systems will be accomplished."

The force of the comparison by Mr. Sprague has already been lost, following great improvements in design since 1906. The handicap in railroad-train service of a heavier motor weight and higher maintenance has been overbalanced by the elimination of expensive feeders and rotary converter substations with attendants.

High cost of electrical equipment had to be reduced before heavy concentrated loads could be handled in long-distance railroad work. The single-phase series and repulsion types of motor were necessary in the development of the art. It was fruitless to try to block the way; but it was wise to state the handicaps which then existed, and to present the worst side of the single-phase commutator motor.

## COMPARISONS OF MOTORS.

Railway motors are compared in a pertinent and relevant way when placed on the following basis:

Weight per h.p. at a given peripheral speed.

Weight of transformers and of all auxiliary apparatus.

Weight of complete motor equipment for a given train weight.

Dimensions; motor clearance for a given driving wheel.

Peripheral speed of armature for a given train speed.

Air gap; bearing lengths and area; weight on bearings.

Power factor at all loads.

Design, size, and guarantee on commutator and brushes.

Time during which 150 per cent. of full-load torque can be sustained (*a*) with motors locked, (*b*) at low speeds, in starting a freight train.

Operation—heating, sparking, vibration, efficiency.

Performance—speed-torque-current relation.

Control scheme to obtain variable speed and uniform acceleration; efficiency of control, if in rapid transit service.

Cost of the equipment for the electric system—the motors, transformers, contact line, and rotary converter substations.

Cost of the power service per ton-mile or per seat-mile, based on the stops per mile, cars per train, schedule, etc.

### RATING OF MOTORS.

**Railway motor rating** has for its basis the *mechanical* h.p. output which the motor will deliver for 1 *hour*, with a rise in temperature above the surrounding air not exceeding 90° C. at the commutator and 75° C. at any other point of the motor. This 1-hour rating indicates the maximum output which the motor should be called upon to develop during acceleration.

**A. I. E. E. standardization rules** call for rating by tests, with natural ventilation, in a room having a temperature of 25° C., with the motor covers removed, and at the rated voltage and cycles. The h.p. is measured at the drivers, and gear and bearing losses are part of the motor losses. Factory tests are made on typical runs under cars or locomotives. Tests have now been made under all conditions of railway service. Service conditions are calculated and the heat developed in the motor, and the conduction and convection of this heat thru the frames, for a series of typical runs, can be estimated closely. The heat losses are those caused by the current in the field, armature, and brush contacts, the friction of air, brush, and bearings, and the magnetic losses in the iron. The root-mean-square of the heat units which are lost in a given time or run must be balanced by the radiation from the frames.

**The capacity** required in a motor is measured by the load which it will carry continuously, at a fixed voltage, with a rise in temperature within safe limits. The motor is then suitable for any service in which the square root of the mean square current at any equivalent voltage are less than this continuous capacity. The instantaneous loads must also be within the commutating limits. This capacity is determined by a shop test, made with covers open, in which the rise in resistance of the motor windings at the end of a 1 hour run will not exceed 40 per cent. The rise in temperature of any part except the commutator will not exceed 75° C., by thermometer. Owing to the improved ventilation which is obtained on a moving locomotive or car, the rise in temperature of the windings at the end of a 1-hour run will not exceed about 75° C., as determined by increase in resistance, or about 55° C. by thermometer.

**Comparisons based on the one-hour rating** are misleading until the following matters are considered:

a. Weight affects rating. A heavy motor has a large thermal storage capacity, and requires more heat units to raise its metal to a given temperature in an hour than a light-weight motor of the some rating. The continuous capacity of the lighter motor under forced draft will be the greater.

b. Covers are to be off, by the Institute rules, but in service covers

are either solid or full of large holes. The 1-hour capacity is about 20 per cent. less with covers on than with covers off.

c. Temperature measurements with a thermometer on the core surfaces of the motor show a lower temperature than that determined by the rise in resistance. The latter gives an accurate average of internal and surface temperature.

d. Speed-torque characteristics may confuse the ratings. For example, series motors are rated at less than one-half their maximum speed, while three-phase motors are rated at their maximum speed. Thus the 1-hour h.p. rating of direct-current and single-phase appears at a great disadvantage in such comparisons. The New Haven geared freight locomotive (071) has a continuous capacity of over 1120 h.p., corresponding to a tractive effort of 12,000 pounds, and a speed of 38 m. p. h., yet the maximum tractive effort in starting is over 50,000 pounds. A three-phase, two-speed locomotive having this maximum tractive effort and this maximum speed might be called a 2500-h.p. locomotive, and yet it would not have greater service capacity than the single-phase locomotive.

e. Voltage affects rating. For example, the G.E.-205 direct-current motor is rated 90 h.p. on 500 volts, 100 h.p. on 600 volts, and only 75 h.p. on 1200 volts, more insulation being required for the latter voltage. Again, the G.E.-69 motor is rated 200 h.p. on 500 volts, 240 h.p. on 600 volts, and 260 h.p. on 660 volts.

**Continuous capacity** of railway motors is recognized by the American Institute in the following:

"The continuous capacity of the motor is given in terms of the amperes which it will carry when run on a testing stand—with covers on or off, as specified—at different voltages, say, 40, 60, 80, and 100 per cent. of the rated voltage, with a temperature rise not exceeding 90° at the commutator and 75° at any other part, provided the resistance of no electric circuit in the motor increases more than 40 per cent."

The author recommends that specifications allow the use of a definite quantity of forced air, at a specified air pressure, for cooling; and further that the run be at full rated voltage, since in practice it is found that runs on lower voltages, either alternating or direct, are decidedly misleading, and, in alternating-current practice, are generally valueless.

**Ventilation of motors** raises the capacity because the permissible output is limited by the maximum temperature rise. In the S. K. C. type of motor, designed by Dodd, natural ventilation was obtained by leaving both ends of the armature open for the entrance of air, and there were ducts thru the frame of the motor, which registered with the ducts in the armature perpendicular to the shaft. As a result of unusually good ventilation, the 10-hour rating of this motor was about

50 per cent. of its 1-hour rating, with the same heating, as compared with a 10-hour rating of but 35 per cent. of the 1-hour rating for small railway motors.

Artificial circulation of air, by forced draft from a fan located either on the armature shaft or external to the motor, is used to drive out the heat. Artificial ventilation, however, does not increase the rating more than 10 per cent. during the first hour's run, but it is of great value during the subsequent hours of continued service.

Ventilation by means of fans in each motor, on the armature shaft, is not satisfactory for series motors, because as the load increases the speed and amount of air cooling is greatly decreased. Ventilation of railroad

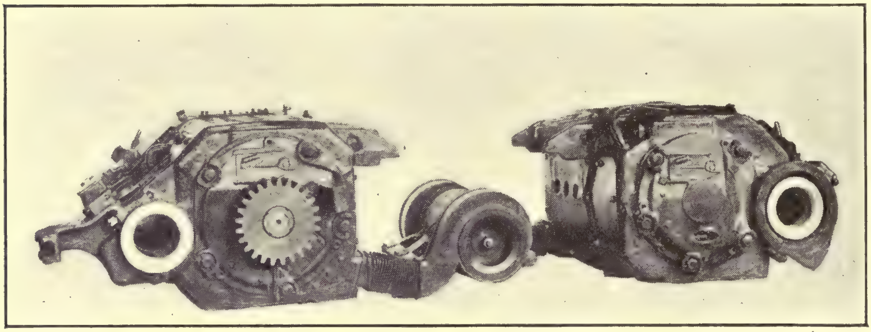


Fig. 42.—Pennsylvania Railroad Motor Equipment and Forced Draft Fan. Used on motor-car trucks in New York-Long Island service. Axle centers 8 1/2 feet. Entire axle enclosed. Motors, direct-current, 215-h. p. each.

motors and transformers is therefore performed by independent motor-driven centrifugal blowers. These furnish air to the motors, at low pressure and velocity, thru a flexible conduit made of wire reinforced canvas. Clean air from points below the roof is used.

Ventilation by forced draft is effective for cooling, not only while the motor is on the heavy or up-grade service, but while the motor is running without current on the down grade, or is standing or waiting to take another load in regular service or up the grade.

Pennsylvania Railroad motors on cars for service on the New York Division use forced draft obtained by means of a blower outfit, consisting of a $1\frac{1}{2}$h.p., 2,250 r. p.m. motor, to the shaft of which at each end, a blower fan 9 inches in diameter and 3 inches wide is attached. Each of these fans is capable of forcing between 400 and 500 cubic feet of air per minute thru the motor, to which it is flexibly connected. The motor is mounted on the truck below the bolster. The installation is of particular interest as being the first where forced ventilation has been used for car motors on such a large scale. The 1-hour rating of the motor is 215 h. p. but this is raised by means of forced ventilation to about 250 h.p.

RATING OF LARGE ELECTRIC MOTORS COMPARED.

| Name of railroad company. | Current volts cycles. | Ventilation. | Continuous h.p. rating. | 1-hour h.p. rating. | Ratio of continuous to 1-hour h.p. |
|---|---|---|---|---|---|
| New York Central...... | DC | Natural .. | 1200 | 2200 | .55 |
| | 600V | .......... | 1166 | 2200 | .53 |
| Michigan. Central....... | DC | Natural .. | 475 | 1100 | .43 |
| Baltimore & Ohio, 1910. | 600V | .......... | .......... | ........ | ............ |
| Pennsylvania........... | DC | Natural .. | 1600 | 2500 | .64 |
| | 650V | .......... | 1200 | 2060 | .58 |
| Valtellina.............. | 3–P | Natural .. | .......... | 1500 | ............ |
| | 15–C | .......... | .......... | ........ | ............ |
| Giovi................. | 3–P | Forced ... | 1150 | 1980 | .58 |
| | 15–C | .......... | .......... | ........ | ............ |
| Simplon............... | 3–P | Natural .. | .......... | 1700 | ............ |
| | 16–C | .......... | .......... | ........ | ............ |
| Great Northern......... | 3–P | Natural .. | 1000 | 1700 | .59 |
| | 25–C | Forced ... | 1500 | 1900 | .79 |
| New Haven: Passenger . | 1–P | Forced ... | 800 | 960 | .83 |
| Freight.... | 25–C | Forced ... | 1120 | 1260 | .89 |
| Freight.... | .......... | Forced ... | 1130 | 1350 | .84 |
| Grand Trunk........... | 1–P | Forced ... | 570 | 720 | .79 |
| | 25–C | | | | |
| Spokane: 1906 Freight.. | 1–P | Forced ... | 385 | 500 | .77 |
| 1908 Freight.. | 25–C | Forced ... | 560 | 680 | .83 |
| Pennsylvania, 1907..... | 1–P | Forced ... | 620 | 940 | .66 |
| | 15–C | | | | |
| Southern Ry., France... | 1–P | Forced ... | 1200 | 1600 | .75 |
| | 15–C | | | | |
| Baden State, Weisental.. | 1–P | Forced ... | 780 | 1050 | .74 |
| | 15–C | | | | |
| A. E. G............... | 1–P | Forced ... | 1000 | 1400 | .71 |
| | 25–C | | | | |

New York Central is estimated by Hutchinson and by Sprague.
Pennsylvania normal field conditions are distinguished from full field.
Alternating-current direct-current motors are here rated on alternating current.
Giovi locomotive motors are rated by resistance measurements.
Forced draft requires closed motor frames.
The table was compiled with care, yet in some cases the accuracy is questioned.

A. I. E. E. 1-hour rating is not in general use for large 600-volt direct-current, closed locomotive motors, nor for alternating single-phase and three-phase motors; and the rating is often on forced draft, which is 5 to 16 per cent. higher.

RATINGS OF LARGE RAILWAY MOTORS WITH FORCED DRAFT.
Comparison: Temperature of air 25° C; of motor 100° C.; A. I. E. E. rules.

| Motor. | Direct. | Alternating. |
|---|---|---|
| 1-hour rating, natural draft | 100 | 100 |
| 1-hour rating, forced draft | 105 to 110 | 105 to 118 |
| Continuous rating, natural draft | 44 to 64 | 50 to 58 |
| Continuous rating, forced draft | 70 to 83 | 73 to 88 |

The data are approximate, yet they are valuable for comparison. Results are affected by the shape, size, and system, as is shown later.

The ratio of ratings of alternating-current motors with and without forced draft is not greatly affected by the size, but for direct-current motors the ratio depends largely on the mechanical design of the frame.

The increase in the continuous rating by the use of forced draft is about 55 per cent. This great increase indicates clearly that in the future all large railway motors, including direct-current motors, will use forced draft because of the lower cost and weight, and safety of insulation.

All railway motors for train service should be given a continuous rating on forced draft. That is the real basis for comparison.

Single-phase motors are rated on their output with alternating current, but when they are designed for interchangeable work, both alternating-current and direct-current rating are given.

The ratio of 300-volt direct-current to 235-volt alternating-current rating or output is about 1.50 on an average.

Ratings are often compared by commercial engineers as follows: Eighty per cent. of the 1-hour A. I. E. E. rating gives the continuous rating with forced draft.

Direct-current street car motors, with natural draft, have a continuous rating of 33 to 43 per cent. of the 1-hour rating.

**Ratings based on a continuous load** or tractive effort are preferable for electric locomotives which make long runs.

**Selection of the requisite motor capacity** involves a careful study or comparison of the following:

Service: single car or train; city street or right-of-way; express or local; freight or passenger; city, suburban, interurban, or railroad; stops per mile; time of stops.

Routes, distances, grades, curves.

Weights of motor cars, locomotives, coaches, and freight cars.

Speed schedule, and layovers.

Equipment: motors per train, gearing, drives.

The capacity required of motors for a given service cannot be considered in this work. Authorities to be recommended:

PARSHALL AND HOBART: "Electric Railway Engineering," Chapter IV.
DAWSON: "Electric Traction for Railways," Chapter IV.
WILSON AND LYDALL: "Electrical Traction," Chapter XVIII.
Carter: Predeterminations in Railway Work, A. I. E. E., June, 1903.
Renshaw: Railway Motors in Service, A. I. E. E., June, 1903.
Armstrong: High-Speed Railway Problems, A. I. E. E., June, 1903.
Armstrong: Heating of Motors (valuable curves), A. I. E. E., June, 1902.
Hutchinson: Temperature Rise of Railway Motors, A. I. E. E., Oct., 1903.
See "Power Required for Trains" and Literature which follow.

## MECHANICAL AND ELECTRICAL DATA.

### NAMES AND RATING OF MOTORS.

Years 1885 to 1895.

Direct-current, 500-volt, Standard-gage Street Railway Motors.

| Name of manufacturer. | Motor number. | 1-hour h.p. | Year built. | Location, type, or detail of construction. |
|---|---|---|---|---|
| Daft............. | 1 | 8 | 1885 | Baltimore, Md. |
| Sprague.......... | 5 | 7 | 1888 | Richmond, Va. |
| | 6 | 15 | 1890 | Many cities. |
| Thomson-Houston | F–30 | 15 | 1889 | Double-reduction gear. |
| | SRG 30 | 15 | 1890 | Single-reduction gear. |
| | SRG 50 | 25 | 1891 | Single-reduction gear. |
| | WP 30 | 15 | 1891 | S.R.G. and well enclosed. |
| | WP 50 | 25 | 1892 | S.R.G. and well enclosed. |
| Wenstrom........ | 4-pole | 15 | 1890 | Slotted armature core. |
| Short-Walker..... | 3 | 15–25 | 1890 | Gearless. |
| | 4 | 30 | 1895 | Geared. |
| | 10 | 50 | ....... | Geared. |
| | 15 | 80–100 | 1890 | Brooklyn Elevated. |
| | | Years 1890 to 1900. | | |
| Westinghouse .... | 1 | 15 | 1890 | Double-reduction geared. |
| | 3 | 20 | 1891 | Open-type; series-connected; machine-wound coils; 4-pole. |
| | 12–A | 25 | 1893 | Open type, cast iron. |
| | 38 | 38 | 1895 | Open type, cast iron. |
| | 38–B | 40 | 1899 | Laminated poles. |
| | 49 | 35 | 1897 | ........................... |
| | 50–B | 150 | ....... | ........................... |
| | 56 | 60 | ....... | ........................... |
| | 69 | 30 | ....... | Steel frames. Replaced 3 and 12. |
| | 68 | 38 | ....... | ........................... |
| | 76 | 75 | ....... | ........................... |

NAMES AND RATING OF MOTORS.—Continued.
Years 1890 to 1900.

| Name of manufacturer. | Motor number. | 1-hour h.p. | Year built. | Location, type, or detail of construction. |
|---|---|---|---|---|
| Westinghouse.... | 83 | 110 | ...... | ........................... |
| | 92 | 35 | ...... | ........................... |
| | 93 | 50 | ...... | ........................... |
| | 101 | 40 | ...... | ........................... |
| | 121 | 85 | ...... | ........................... |
| General Electric.. | 800 | 27 | 1892 | Enclosed 4-pole motor. |
| | 1000 | 35 | 1894 | ........................... |
| | 1200 | 38 | 1893 | ........................... |
| | 2000 | 125 | 1893 | Intramural Ry., Chicago. |
| | 51 | 80 | 1896 | Four-pole. Replaced by G.E. 73. |
| | 52 | 27 | 1896 | Ventilating ducts in armature. core. Replaced G.E. 800. |
| | 55 | 160 | 1896 | Nantasket Beach, near Boston; Buffalo & Lockport, New York; Akron, Bedford & Cleveland. |
| | 57 | 52 | 1897 | ........................... |
| | 58 | 37 | ...... | ........................... |
| | 64 | 60 | ...... | ........................... |
| | 67 | 38 | 1899 | Replaced G.E. 1000. |
| | 68 | 175 | ...... | ........................... |
| | 78 | 35 | ...... | ........................... |

DIRECT-CURRENT, 600-VOLT, COMMUTATING-POLE RAILWAY MOTORS, 1911.

| Horse power. | General Electric. | Westinghouse. | Allis. |
|---|---|---|---|
| 50 | 202–213–216–219 | 307–312–319–B | 501 |
| 60 | .................... | 306–316 | ................ |
| 70 | 210–218 | 305–310 | ................ |
| 75 | 214 | .................... | ................ |
| 90 | .................... | 304–317 | ................ |
| 100 | 205 | 303 | ................ |
| 110 | .................... | 303–A | ................ |
| 125 | 206 | .................... | ................ |
| 140 | .................... | 302 | ................ |
| 160 | 207–211 | .................... | ................ |
| 175 | .................... | 301–B | ................ |
| 225 | 208–212 | 300–B–308 | ................ |
| 240 | 69 | .................... | ................ |
| 275 | 209 | .................... | ................ |
| 1000 | .................... | 315 | ................ |

The 100 h.p. G.E.-205 motors are rated 75 h.p., and the 160 h.p. G. E.-207 motors are rated 125 h.p., when used two in series on 1200 volts.

STANDARD THREE-PHASE RAILWAY MOTORS. Year 1911.

| 1-hr. h.p. | General Electric | Westinghouse Electric. | Ganz Electric. | Brown Boveri. |
|---|---|---|---|---|
| 150 | ........ | ........ | ........ | Burgdorf Thun. |
| 225 | ........ | ........ | Valtellina ........ | ........ |
| 250 | ........ | ........ | Valtellina (m.c.). | ........ |
| 425 | Great Northern. | ........ | ........ | ........ |
| 550 | ........ | ........ | ........ | Simplon. |
| 600 | ........ | ........ | Valtellina........ | ........ |
| 850 | ........ | ........ | ........ | Simplon. |
| 990 | ........ | Giovi........ | ........ | ........ |
| 1200 | ........ | ........ | Valtellina........ | ........ |
| 1500 | ........ | ........ | Valtellina........ | ........ |

Voltage is 3000, except Great Northern, which is 500.

SINGLE-PHASE 25- AND 15-CYCLE RAILWAY MOTORS.

| 1-hr. h. p. | No. of cycles. | General Electric. Used by | Westinghouse Electric. Used by | Siemens Brothers. Used by | A.E.G., Berlin. Used by |
|---|---|---|---|---|---|
| 50 | 25 | 604. Ballston..... | Long Island........ | ........ | ........ |
| 75 | 25 | 605. Toledo & Chi. Illinois Traction. | 135. Ft. Wayne & Springfield. | Thamshavn ..... | Italian State. |
| 100 | 25 | ........ | 132. Windsor; Erie; Rock Island. | ........ | Prussian State, etc. |
| 115 | 25 | ........ | Swedish State........ | Swedish State... | 151. Hamburg-Altoona. London, B. & S.C. |
| 125 | 25 | 603. Milwaukee; Annapolis; New Canaan. | 148. Spokane & Inland; Chicago, L.S. & S.B. | Hamburg-Alt.... | ........ |
| 150 | 25 | 609. Illinois Traction. | 156. New Haven m.c. Swedish State. | Midland......... | London, B. & S.C. |
| 170 | 25 | ........ | 151. Spokane........ | Oranienburg..... Rotterdam. | ........ |
| 200 | 25 | ........ | ........ | ........ | Prussian State. |
| 225 | 25 | ........ | Grand Trunk........ | ........ | ........ |
| 240 | 25 | ........ | New Haven passenger locomotive. | ........ | ........ |
| 315 | 25 | ........ | 403. New Haven, freight locomotive. | ........ | Oranienburg. |
| 400 | 25 | Experimental..... | ........ | ........ | ........ |
| 675 | 25 | ........ | New Haven, freight.. | ........ | ........ |
| 75 | 15 | ........ | Visalia, m. c........ | ........ | ........ |
| 90 | 15 | ........ | 135. ........ | ........ | ........ |
| 100 | 15 | ........ | ........ | Oberammergau.. | ........ |
| 125 | 15 | ........ | 132. Visalia, locomo. | French Southern | Norway. |
| 150 | 15 | ........ | ........ | ........ | ........ |
| 175 | 15 | ........ | ........ | Oberammergau.. | ........ |
| 200 | 15 | ........ | French Southern m.c. | ........ | ........ |
| 220 | 15 | ........ | ........ | Bernese-Alps.... | ........ |
| 460 | 15 | ........ | 144. Pennsylvania R.R. | ........ | ........ |
| 525 | 15 | ........ | ........ | Wiesental........ | ........ |
| 800 | 15 | ........ | French Southern..... | ........ | French Southern. |
| 1000 | 15 | ........ | ........ | Bernese-Alps.... | Bernese-Alps. |
| | | ........ | ........ | Swedish State... | Prussian State. |
| 1200 | 15 | ........ | ........ | Wiesental........ | ........ |

General Electric motors were withdrawn in 1909.
The list of users, given under "Electric System," is more complete.

WEIGHT OF DIRECT-CURRENT 500-, AND 600-VOLT RAILWAY MOTORS. 1911.

General Electric.

| Motor No. | Rated h.p. 1-hour. | Wt. of arm. | Wt. of motor. | Wt. of 4-motor equipment. | Notes on motor, or on use by railroads. |
|---|---|---|---|---|---|
| 54 | 25 | 395 | 1830 | 8500 | Weight of all motors listed includes |
| 67 | 40 | 600 | 2400 | ........... | gear and gear case, box-type motors and multiple-unit. M. control. |
| 57 | 50 | 704 | 2975 | 14140 | ................................ |
| 98 | 50 | 677 | 3275 | 15870 | ................................ |
| 87 | 60 | 768 | 3510 | 16710 | ................................ |
| 74 | 65 | 845 | 3535 | 17190 | ................................ |
| 73 | 75 | 1175 | 4137 | 19250 | ................................ |
| 66 | 125 | 1327 | 4375 | 21250 | Aurora, Elgin & Chicago. |
| 55 | 160 | 1550 | 5415 | 27050 | Buffalo & Lockport; St. Louis & Belleville. |
| 76 | 160 | 1526 | 5152 | 26000 | ................................ |
| 68 | 175 | ...... | 5302 | 48000 | Boston Elevated; Central London, gearless. |
| 65–B | 200 | 2000 | 12975 | 35400 | Baltimore & Ohio, 1903 geared. |
| 69–B | 240 | 1800 | 6230 | 30700 | Metropolitan District; Interboro Rapid Transit. |
| 65 | 250 | 2840 | 8855 | 35700 | Paris-Orleans, geared. |
| 70 | 360 | 9500 | ...... | 51900 | Baltimore & Ohio, 1895 gearless. |
| 84 | 550 | 7640 | 12400 | 67700 | New York Central gearless; weight of armature without axles and drivers. |
| | | | | 12846 | Motors above No. 200 are interpole. |
| 202–13 | 50 | 600 | 2600 | 14060 | ................................ |
| 216–19 | 50 | 662 | 2887 | 15425 | ................................ |
| 218 | 70 | ...... | 3200 | 15680 | ................................ |
| 210 | 70 | 805 | 3440 | 16252 | ................................ |
| 204 | 75 | ...... | 3080 | 18000 | ................................ |
| 214 | 75 | 894 | 3820 | 19200 | Motor 205, rated 75-h.p. on 1200 volts. |
| 205 | 100 | 1052 | 3950 | 20600 | ................................ |
| 206 | 125 | ...... | 4250 | 23738 | ................................ |
| 207–11 | 160 | ...... | 4740 | 31520 | ................................ |
| 208 | 225 | ...... | 6380 | 30700 | ................................ |
| 212 | 225 | ...... | 6230 | | ................................ |
| 209 | 275 | 3000 | 11600 | 46400 | Michigan Central, locomotive, 1910. Baltimore & Ohio, locomotive, 1910. |

## WEIGHT OF DIRECT-CURRENT 500- AND 600-VOLT RAILWAY MOTORS, 1911.

Westinghouse.

| Motor No. | Rated voltage. | 1-hr. h.p. | Wt. of armature. | Wt. of motor and gears. | Wt. of 4-motor equipment. | R.P.M. at rating. |
|---|---|---|---|---|---|---|
| 12–A | 500 | 25 | 360 | 2205 | 10,250 | 525 |
| 12–A | 500 | 30 | 345 | 2270 | 10,250 | 700 |
| 69 | 500 | 30 | 385 | 1950 | 9,100 | 553 |
| 92–A | 500 | 35 | 475 | 2265 | 10,700 | 530 |
| 49 | 500 | 35 | .......... | 1925 | .......... | 550 |
| 68–C | 500 | 40 | 505 | 2270 | 10,700 | 565 |
| 101–A | 500 | 40 | 585 | 2730 | 12,500 | 520 |
| 38–B | 500 | 40 | 524 | 2350 | 12,150 | 500 |
| 39 | 500 | 50 | .......... | 2900 | 14,200 | .......... |
| 89 | 500 | 50 | 650 | 2900 | 14,200 | .......... |
| 101–D | 500 | 55 | 585 | 2730 | 12,500 | .......... |
| 56 | 500 | 55 | 720 | 3000 | 14,600 | .......... |
| 93–A | 500 | 55 | 778 | 3490 | 15,000 | 468 |
| 305 | 500 | 63 | .......... | 3550 | 16,280 | 495 |
| 305 | 600 | 75 | .......... | 3550 | 16,280 | 600 |
| 112–B | 500 | 75 | 825 | 3400 | 16,000 | 630 |
| 76 | 500 | 75 | 860 | 3480 | 19,000 | 495 |
| 85 | 500 | 75 | 995 | 4500 | 21,640 | 495 |
| 121–A | 550 | 85 | 1220 | 4300 | 19,400 | 620 |
| 70 | 550 | 115 | .......... | 4800 | .......... | .......... |
| 119 | 550 | 125 | 1340 | 4600 | 21,080 | 640 |
| 133 | 550 | 150 | .......... | 5500 | .......... | .......... |
| 114 } 134 } | 550 | 160 | 1525 | 5300 | 26,800 | 625 |
| 86 | 550 | 200 | .......... | 5900 | .......... | .......... |
| 113 | 550 | 200 | 1980 | 6700 | 40,000 | 610 |
| 103 | 600 | 300 | 5300 | 11500 | .......... | .......... |
| 315 | 600 | 1000 | 10950 | 45000 | Two motor. | Penn. R. R. |

R. P. M. = M. P. H. $\times$ gear ratio $\times$ 336 $\div$ driver diameter.

## WEIGHT OF DIRECT-CURRENT RAILWAY MOTORS, 1910.

Allis-Chalmers.

| Motor No. | Rated voltage | 1-hr. h.p. | R.P.M. at rating. | Wt. of armature. | Wt. of motor and gears. | Wt. of 4-motor equipment. |
|---|---|---|---|---|---|---|
| 501 | 600 | 50 | .......... | .......... | 2720 | 12,560 |
| 301 | 500 | 40 | 550 | .......... | 2630 | 12,300 |
| R–35 | 500 | 40 | 523 | 660 | 2490 | 12,200 |
| R–50 | 500 | 55 | 575 | 760 | 2870 | 14,100 |
| R–75 | 500 | 75 | 510 | 1140 | 3770 | 18,500 |

Siemens Brothers.

| | | | | | | |
|---|---|---|---|---|---|---|
| 54–S | 500 | 35 | 545 | 400 | 1840 | .......... |
| 92–L | 500 | 52 | 475 | 640 | 2870 | .......... |
| 92–L | 750 | 56 | 520 | 640 | 2870 | .......... |
| 72 | 500 | 58 | 490 | 540 | 2325 | .......... |
| 17–30 | 750 | 58 | 800 | 665 | 3175 | .......... |
| 92–S | 750 | 75 | 710 | 735 | 3540 | .......... |
| 150 | 900 | 130 | 700 | .......... | 5500 | .......... |

## WEIGHT OF THREE-PHASE RAILROAD LOCOMOTIVE MOTORS.

| 1-hr. h.p. | Motors used. | Wt. per motor. | Speed R.P.M. | Wt. of all elec. equip. | Manufacturer. | Railroad installation. |
|---|---|---|---|---|---|---|
| 150 | 4 | 11,000 | 128 | .......... | Ganz | Valtellina, 1902 |
| 150 | 4 | 8,800 | 300 | .......... | Brown | Burgdorf. |
| 225 | 4 | 11,000 | 300 | .......... | Ganz | Valtellina(motorcars). |
| 425 | 4 | 14,950 | 358 | 73,200 | G.E. | Great Northern. |
| 550 | 2 | 25,000 | 224 | 65,000 | Brown | Simplon, 1907. |
| 600 | 2 | 27,800 | 224 | 66,000 | Ganz | Valtellina, 1904. |
| 850 | 2 | 27,520 | 270 | 78,000 | Brown | Simplon, 1909. |
| 990 | 2 | 27,000 | 224 | 60,000 | Westing | Giovi. |
| 1200<br>1500 | 1<br>1 | .... | 224 | 54,000 | Ganz | Valtellina, 1906. |

WEIGHT OF SINGLE-PHASE RAILWAY MOTORS.

Westinghouse, 25 Cycles.

| Motor No. | 1-hr. h.p. AC | 1-hr. h.p. DC | Wt. of armature. | Wt. of motor and gears. | Wt. of 4-motor equipment. | Installation for railroads. |
|---|---|---|---|---|---|---|
| | 50 | .... | .......... | .......... | .......... | Long Island: Sea Cliff Div. |
| 135 | 75 | .... | .......... | 4500 | .......... | Bergamo-Brembana. |
| 132 | 100 | 156 | 1865 | 5000 | .......... | Baltimore & Annapolis. Rock Island Southern. |
| 148 | 125 | 0 | .......... | 6100 | .......... | Chi. Lake Shore & S. Bend. |
| 133 | 135 | 94 | 2705 | 6025 | 41,200 | Spokane & Inland loco. |
| 156 | 150 | .... | 1500 | 7950 | 55,405 | New Haven motor-car. |
| ...... | 150 | 0 | .......... | 13830 | .......... | New Haven Switcher. |
| 151 | 170 | 150 | 3570 | 10420 | 47,557 | Spokane & Inland loco. |
| 137 | 225 | 0 | 5095 | 15660 | 3 motors. | Grand Trunk locomotive. |
| 130 | 240 | 360 | 5850 | 16710 | 66,840 | New Haven passenger. |
| 403 | 315 | .... | .......... | 19770 | 79,000 | New Haven geared freight. |
| | 675 | .... | .......... | 41600 | 83,200 | New Haven crank-type, two motors, freight. |

Westinghouse, 15 Cycles.

| Motor No. | 1-hr. h.p. AC | 1-hr. h.p. DC | Wt. of armature. | Wt. of motor and gears. | Wt. of 4-motor equipment. | Installation for railroads. |
|---|---|---|---|---|---|---|
| 135–A | 90 | ... | .......... | 4500 | 31,000 | .......................... |
| 132 | 125 | ... | .......... | 5300 | 35,650 | Visalia locomotive. |
| 156 | 150 | .... | 2250 | 7468 | 54,100 | Weight with quill. |
| 144 | 460 | .... | 9350 | 19500 | .......... | Pennsylvania R.R. gearless. |
| ...... | 800 | ... | .......... | .......... | 59,200 | French Southern, 2-motor freight locomotive. |

WEIGHT OF SINGLE-PHASE RAILWAY MOTORS.

General Electric, 25 Cycles.

| Motor No. | 1-hr. h.p. | Wt. of armature. | Wt. of motor and gears. | Wt. of 4-motor equipment- | Installation for railways. |
|---|---|---|---|---|---|
| 604 | 50 | 1200 | 4500 | .......... | Schenectady-Ballston. |
| 605 | 75 | .......... | 5000 | .......... | Toledo & Chicago. |
| 603 | 125 | 2000 | 7000 | .......... | Milwaukee; Annapolis; New Canaan. |
| | 125 | .......... | 6000 | .......... | New Haven, motor-car. |
| 609 | 150 | .......... | 8200 | .......... | Illinois Traction. |

Weight of New Haven 4-motor, No. 156, 25-cycle equipment without direct-current control equipment is 47,250 pounds.

WESTINGHOUSE MOTORS. ELECTRICAL DATA.
Direct-current, 500–600 Volts.

| Motor No. | 1-hr. h. p. | Arm. diam. | Bore of poles. | Field coil turns. | Size of wire or strap. | Field Res., ohms. | Armature slots. | Coils per slot. | Armature turns; sized wire or bar. | Arm. Res. ohms. |
|---|---|---|---|---|---|---|---|---|---|---|
| 92–A | 35 | 13 | 13 3/8 | 125 | 5/16x1/2 | .340 | 41 | 3 | 3 turns 10 | .340 |
| 101–B | 40 | 14 | 14 3/8 | 110 | 5/16x5/8 | .296 | 37 | 3 | 3 turns 9 | .290 |
| 93–A | 55 | 15 | 15 3/8 | 78 | 3/64x1 1/4 | .166 | 45 | 3 | 3 turns 10 | .148 |
| 112–B | 75 | 15 | 15 3/8 | 60 | 1/16x1 1/4 | .094 | 45 | 5 | 2 3/64x1/2 | .090 |
| 121–A | 90 | 17 | 17 3/8 | 49 | 1/16x1/4 | .087 | 41 | 5 | 1 3/64x5/8 | .070 |
| 119 | 125 | 17 | 17 7/16 | 42 | 3/32x1 3/8 | .051 | 37 | 5 | 1 1/16x5/8 | .050 |
| 114 | 160 | 17.5 | 18 | 40 | 7/64x1 3/4 | .035 | 33 | 5 | 1 1/10x1/2 | .037 |
| 113 | 200 | 19 | 19 1/2 | 36 | 1/8x2 | .025 | 31 | 5 | 1 1/8x1/2 | .030 |

| Motor No. | Commutator data. | | | | Brush section. | Armature bearings at | | Shaft at pinion. |
|---|---|---|---|---|---|---|---|---|
| | Diam. | Length. | Bars. | Brushes. | | Commutator. | Pinion. | |
| 92–A | 9 | 3 5/8 | 123 | 2 | 1/2x1 1/2 | 3 x7 1/2 | 3 x6 1/2 | 2 3/4 |
| 93–A | 10 1/4 | 4 11/16 | 135 | 2 | 1/2x2 | 3 3/4x8 7/16 | 3 1/2x7 | 3 3/8 |
| 112 | 12 1/2 | 5 1/2 | 225 | 2 | 1/2x2 | 3 3/4x8 7/16 | 3 1/2x7 | 3 3/8 |
| 121 | 14 1/2 | 6 | 205 | 3 | 1/2x1 3/4 | 4 x8 1/2 | 3 3/4x7 | 3 3/4 |
| 119 | 14 1/2 | 6 23/32 | 185 | 3 | 1/2x2 | 4 x10 | 3 3/4x7 | 3 3/4 |
| 114 | 14 1/2 | 6 3/4 | 165 | 4 | 5/8x2 | 4 1/2x10 | 3 3/4x7 1/4 | 4 1/8 |
| 113 | 16 3/4 | 9 11/16 | 155 | 4 | 5/8x2 1/4 | 4 3/4x10 | 4 x7 | 4 3/8 |

Length of commutator is from end to lug. Two brushes are used per holder.

Wedges are used to hold armature coils of 25- to 75-h. p. motors, and bands on larger motors, with 4 to 5 bands on the core, and one band at each end of coils.

Several modifications exist for each motor.

## DEVELOPMENT OF RAILWAY MOTOR DESIGN.

In general, railway motor design must embrace machinery which furnishes the greatest possible output at the least expense in first cost and in performance. This involves the best materials, the highest practical speeds, and the best arrangement of the materials in the design. Steel with very high permeability, 100,000 lines per square inch, in both solid and sheet form is utilized. Mica and asbestos are the insulating materials having the greatest heat-resisting qualities. High speeds are economical when expensive constructive features are reduced. Weight may be decreased by more efficient materials, interpole motors, artificial cooling, and lower cycles. When weight of motors used in rapid transit service is over-reduced, mechanical and electrical excellence are sacrificed.

Some of the details of development follow:

1. **Magnet frames** of direct-current motors were originally bipolar,

and of cast iron. Sprague motor frames were of good wrought iron. Enclosed Thomson-Houston waterproof motors of 1891, and the G.E.-800 motor of 1892, and all modern motors have used cast steel frames largely because the improved magnetic qualities of steel allowed a reduction in the weight and space. Some of these had consequent poles, but they were soon abandoned for the standard, 4-pole motor, which was introduced in the Westinghouse No. 3 open motor of 1891.

Field frames of direct-current motors are divided as follows: Small motors, 30- to 80-h.p., have the cast steel frames divided horizontally, and the center lines of the 4 poles are at an angle of 45 degrees with the horizontal; and larger motors either have their frames split, at an angle of 45 degrees, and 2 poles set horizontally and 2 vertically, or a box type frame is used which is not split. Small motors are opened by swinging the lower half downward, to the repair pit, on hinges which are placed on the side opposite the axle. Armature bearings are bolted to the upper or to the lower field. Large motors are inspected by running the truck out from under the locomotive or car. If the field is divided, the upper half is opened to get at the fields and armature. Box type or solid fields require that the motor be removed entirely from the truck and the armature to be taken out at one end. Some motor frames, G.E. 70 and 74 of 1904, are split horizontally, well above the center line, to get a small upper frame, for facilitating quick repair work.

Box type frames were introduced about 1898. They have a single magnetic casting of soft steel, in the form of a cube with well rounded corners. Maximum capacity, minimum space, rigidity of frame, and perfect alignment of brush-holders and bearings are obtained. Housings for the bearings are bolted against well-fitted cylindrical heads on the field frames. Armature, field coils, and pole pieces are removed thru the end of the frame. The armature is taken out by removing one frame head and then lifting and sliding the armature horizontally thru the opening; or the motor is set on end and the armature lifted vertically; or, again, the motor is put in a lathe, the armature is supported on its center line, and the motor frame rolled parallel to the shaft.

**Magnet frames of alternating-current motors** consist of an outer steel casing forming a structural frame for the motor. The frame encloses a cylindrical field ring or stator built up of thin annular laminations, insulated from each other by japan or enamel, and securely bolted together.

Single-phase and three-phase fields of 50- to 150-h.p. motors are made in one piece, and cannot be divided like those of direct-current motors. Armatures are taken out as in box type frames.

Gearless motor fields and frames are split horizontally and are removed in halves, the field windings being disconnected for that purpose. New York, New Haven & Hartford motor frames for gearless passenger

locomotive are split, but the geared and the crank type freight locomotive motor frames are solid. The frames of the motors for the freight

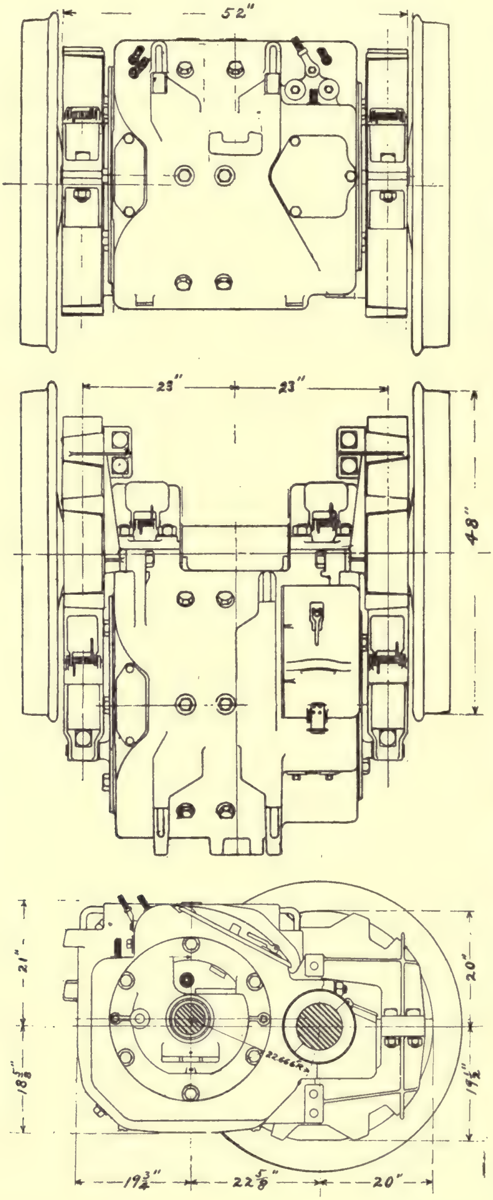



Fig. 43.—Drawing of G. E.-209, D. C., 600-volt, 275-h. p. Railway Motor Used on the 1910 Baltimore and Ohio, and Michigan Central Locomotives.

locomotive are built up of steel plates and structural angles. The motor is stiff, and light in weight, and the field laminations are well exposed.

**Enclosure** of the entire motor has finally been effected, at first by protecting it with canvas or galvanized iron, and then by the use of most of the magnet frame, in the "waterproof motor" of 1891. Finally the frame entirely enclosed the motor. The covers over the commutators of small motors are closed, while the covers of large motors and also the upper frames often have many half-inch holes. See Ventilation.

The axle is enclosed on the Pennsylvania motor cars to keep out dust.

Forced draft has been adopted to keep out the dust, to ventilate, and to cool large motors. Examples: 210-h.p., direct-current types for Long Island Railroad; 275-h.p., direct-current types for Michigan Central Railroad; 240-h.p. single-phase types, for New York, New Haven & Hartford Railroad; 325-h.p., three-phase types, for Great Northern Railway. Motors located up in the locomotive are not enclosed.

2. **Poles of direct-current motors** were originally of cast or wrought iron or steel, but are now of laminated steel with magnetically saturated faces, bolted on the cast-steel field frame. This plan was introduced in the Westinghouse-38 motor of 1899.

**Commutating poles** were developed about 1907. A small auxiliary interpole or commutating pole placed between the main poles, holds the neutral point and thus reduces the sparking. Non-commutating pole motors cannot be relied on for more than 50 to 75 per cent. overload, to make up lost time or to accelerate on heavy grades, while commutating pole motors will take care of from 150 to 200 per cent. overload for emergency intervals without destructive sparking. Commutating pole motors, without other changes, allow the use of about 50 per cent. greater voltage per bar; but the proportion of copper to steel is increased.

**Poles of alternating-current motors** are enclosed by a cylindrical steel ring. They are built of thin, annular laminations held by bolts which run parallel to the shaft. The interior portions of the punchings are shaped to form four or more poles, which are slotted for the reception of the field windings. They are often split between the middle of two field coils (not between adjacent coils), and only a single connector of the compensation windings is disturbed. St. Ry. Journ., Aug. 28, 1907, p. 281.

There are no inner projecting poles in single-phase motors. There are no fixed poles in three-phase motors, since the field revolves or progresses electrically.

**Sparking** at commutators is the cause of most all motor trouble. It disintegrates brushes, burns copper, and increases the brush friction. The copper and carbon dust works into windings, brush holders, and insulation, and causes flash-overs and breakdown of insulation. With good commutation, soft high-grade carbon brushes are used, brush tension and vibration are greatly reduced, and a high glaze, which prevents commutator wear and increases the life of the brushes and commutator, is formed.

3. **Field coils** with both shunt and series windings were found in the first direct-current railway motors. Series motors of 1885, built by Field, and the 1888 Sprague motors had 2 fields and 6 field coils which, in starting a car, were first connected in series, partly for use as resistance, and then in multiple groups. Thomson-Houston motors used field loops by means of which the turns per coil were varied. Magnets were horseshoe-shaped and had two coils until about 1891. Railway motor field coils were simplified about 1890 by a change to a plain series winding on brass spools. The cotton-covered, wire-wound coils were changed to mica- and asbestos-covered copper straps.

The modern coil is of the mummified type; and it is heavily wrapped and made complete without any outside metallic retaining spool, except for some locomotive motors. The coil is placed in a vacuum which exhausts the moisture and air, after which the insulating compound, which is forced in, penetrates every part of the coil. High temperatures and a long time are required for this treatment. The coil then resists the action of water and air to which it is exposed, yet radiates the heat. It is compact, and vibration and chafing of wires are prevented, yet it will not warp when heated repeatedly by overloads. Outside protection against mechanical injury is obtained by wrapping tape, or cotton webbing thoroly filled with japan. The coil is clamped to the frame by heavy, flat spring hangers after the pole pieces are bolted in the motor.

Field coils of three-phase motors are similar to those of generators and are insulated with tape and mica, and are mummified. The coils are of the distributed type. See specifications of Giovi locomotives.

Field coils of single-phase motors are distributed windings, carried in slots in the pole faces. The field windings are in two independent sections, the main field for energizing and producing the effective magnetic field and the other, an auxiliary, or compensating winding, which simply balances the armature reaction on the field. In other words, the compensating windings counteract the armature inductance, and improves the commutation by compensating the armature reaction; and the field distortion is thereby reduced. The coils of the main exciting windings are connected in parallel to reduce the self induction. Many methods of winding are used in the repulsion and series type of single-phase motors.

4. **Air gap length,** between the armature and stator, are grouped. Direct-current designs use 6/32 inch for 75-h.p.; 7/32 inch for 125-h.p.; 8/32 inch for 160- to 225-h.p.; 6/32 inch for 275-h.p. Michigan Central locomotive motors; 8/32 inch for 550-h.p. New York Central and 9/32 for 1250-h.p. Pennsylvania locomotive motors.

Single-phase motor designs use about 4/32 inch for the 240-h.p. New Haven passenger locomotive motors; 3/32 inch for 390-h.p. Weisental locomotive motor; and for G. E.-603, 125-h.p. motors.

Three-phase motor designs use smaller air gaps. Valtellina 200- to 600-h.p. motors use 1.5 mm., Simplon Tunnel 450-h.p. motors 1.5 mm., while Great Northern Railway 425-h.p. motors use 1/8 inch or 3.2 mm.

Air gaps for comparable motors are:

Direct-current, 1/4 inch or .250 inch.

Single-phase, 1/8 inch or .125 inch.

Three-phase, 2.1 mm. or .083 inch.

The proportion is as 1000 to 500 to 333.

In the 15-cycle motor, a considerably larger air gap can be used than on the 25-cycle, without reducing the power factor below desirable limits.

5. **Armatures** of small motors were at first of large diameter. The armature of the Short 35-h.p. gearless motors of 1890 were heavy, rigid, and inaccessible, and of large diameter—about 36 inches. The famous "W.P.," 25-h.p. single-reduction geared motor of 1891 had a diameter of 19 1/4 inches; and the flywheel effect, in starting and stopping, of such armatures was a bad feature. Cores were soon reduced in diameter and increased in length to permit rapid acceleration and retardation. The clearance between frame and roadbed was thereby increased. Ventilation of armature cores by means of radial slots did not receive sufficient consideration until the Walker motor No. 4 was developed in 1895 and the G. E.-52 motor in 1896. See Ventilation, under "Rating of Motors." See "Armature Speed," in section 9, which follows.

Armature cores of direct-current, single-phase and three-phase motors are made up of soft laminations, often insulated with japan. They are generally mounted by fitting and carefully forcing the laminated core and commutator shell on a one-piece, cast-steel spider. The shaft is then independent, and is forced on under a pressure of 30 to 70 tons and keyed to the spider. Armatures frequently take up most of the space between the drivers. Armature core dimensions are given in the next table.

6. **Armature windings** of the first railway motors had hand-wound surface coils. These have been superseded by machine-wound coils with straight-out barrel winding imbedded between teeth of a slotted armature; and they are formed and insulated before being placed in the core.

Wire-wound armatures of 50- to 90-h.p. motors have three or two turns per coil and usually three coils per slot. Bar- or strap-wound coils are used on large motors, and have one or two coils in the same slot assembled and insulated together. The insulated wire or strap is vacuum-impregnated, treated with insulating compound, tapped, and sealed.

Armature windings of single-phase motors are generally series-drum windings with three coils per slot, as in direct-current motors. The one turn used per commutator segment reduces the inductive effect and the sparking. Great care is taken to secure extreme rigidity.

Strap-wound coils of large armatures are generally divided at the rear.

Binding is required to hold the coils in place, No. 14 to 17 B. & S. gage, tinned, steel wires being used, the number and width depending upon the size and speed of the armature.

Insulations used for motor windings are doubled cotton, tape, paper, asbestos, linseed oil, varnishes, and particularly mica. All of the insulations except asbestos and mica become brittle and char at 100° C. The highest temperature on factory tests, which is safe, is about 100° C. Under service conditions, with the better ventilation, coils run cooler.

7. **Commutators** were originally of small diameter and poorly insulated, but are now long, of large diameter, and have ample stock.

Commutator bars are generally of hard-drawn copper, built up on a cast-steel sleeve, with a steel cone ring and nut for small motors, and a number of tap bolts between two V-rings on larger motors. The wearing depth is from 7/8 to 1 inch. The coil leads are soldered into the bars.

Commutators for single-phase motors conform to direct-current practice, but are larger and wider. Connections between the armature windings and the commutator bars sometimes require resistance leads to reduce the short-circuit current. These leads are insulated like the main armature winding, and are placed in slots beneath the armature winding proper. They are a source of danger when the motor is overloaded for long periods, yet good results are being obtained. Commutators on New Haven locomotives run 100,000 locomotive miles before being turned.

Slotting the hard mica between commutator bars is a recent development, to increase the life of the commutator and the brush. Slotting to a depth of 1/16 of an inch by simple automatic tools increases the life of old motors about 800 per cent., and of new motors 300 per cent.

8. **Brushes** were originally of copper set at an angle with the commutator. Van Depoele introduced carbon brushes in 1884. Good carbon was used as early as 1889.

Sparking at brushes is no longer destructive. The relation of the field magnetism to that of the armature is understood; and the use of the commutating pole in direct-current motors and of compensating coils in single-phase motors keep the neutral point absolutely at the brush contact. The commutating-pole motor has doubled the life of brushes. For data on life and wear, consult Elec.' Ry. Journ., June 19, 1909, p. 1108. The life of carbon brushes averages 15,000 car-miles for direct current, and 8000 for single-phase motors. New Haven locomotive brushes have a life of about 32,000 locomotive miles.

Armatures are so connected in standard four-pole direct-current motors that one pair of brushes holders suffice, where two pairs are required in single-phase motors. The field is often reversed to change the

direction of motion, and to keep the positive lead connected to the same brush. The Deri induction brushes are shifted mechanically.

**Brush-holder** design has been well perfected by the use of rigid supports, by longer creepage distances to prevent flashing thru carbon dust, by the use of mica tubes for internal insulation and of porcelain rings for external protection, and by the use of light but uniform brush pressure over the working range of wear.

Brushes suitable for one motor are not satisfactory for another. Manufacturers offer a complete range of brushes for each motor, and have collected the data required on brush holders, brush sizes, current density, hardness, abrasive qualities, commutator speed, and the commutation or other peculiarities of each motor.

9. **Armature speed** with the first motors was high. It has been reduced by modifying the magnet frames, increasing the number of poles, and lengthening the armature core. The tabular data on speeds given below are of interest in design, particularly those on the comparative peripheral speed of armatures in feet per minute.

SPEED OF ARMATURES OF RAILWAY MOTORS.

| Name of railway. | Motor h.p. | Car m.p.h. | Gear ratio. | Motor r.p.m. | Driver diam. | Arm. diam. | Core width. | Periphera speed arm. |
|---|---|---|---|---|---|---|---|---|
| Early electric.... | 15 | 20 | 12.00 | 2447 | 33 | 12.0″ | 10.0″ | 7690 |
| Modern electric.. | 25 | 30 | 4.00 | 1221 | 33 | 15.0 | 12.0 | 4800 |
| Interurban...... | 75 | 50 | 3.50 | 1780 | 33 | 15.0 | 16.0 | 2225 |
| Interstate....... | 125 | 60 | 3.00 | 1680 | 36 | 17.0 | ....... | 7480 |
| New York Central | 240 | 50 | 1.88 | 877 | 36 | ...... | ....... | .......... |
| New York Central | 550 | 60 | Direct | 458 | 44 | 29.0 | 19.0 | 3470 |
| N. Y. N. H. & H. | 150 | 50 | 3.30 | 1320 | 42 | ...... | ....... | ......... |
| N. Y. N. H. & H. | 240 | 60 | Direct | 320 | 63 | 39.5 | 18.0 | 3310 |
| N. Y. N. H. & H. | 315 | 35 | 2.32 | 187 | 63 | 39.5 | 13.0 | 1935 |
| N. Y. N. H. & H. | 675 | 35 | Crank | 206 | 57 | 76.0 | 13.0 | 4100 |
| Pennsylvania.... | 1250 | 60 | Crank | 280 | 72 | 56.0 | 23.0 | 4100 |
| Michigan Central. | 275 | 35 | 4.37 | 1070 | 48 | 25.0 | 11.5 | 7005 |
| Grand Trunk.... | 240 | 35 | 5.31 | 1007 | 62 | 30.0 | 14.75 | 7910 |
| Great Northern.. | 475 | 15 | 4.26 | 358 | 60 | 35.75 | 16.25 | 3374 |
| Valtellina....... | 1500 | 40 | Crank | 225 | 59 | 68.0 | ....... | 4000 |
| Simplon 1907.... | 550 | 43 | Crank | 238 | 61 | ...... | ....... | .......... |
| Simplon 1909.... | 850 | 43 | Crank | 320 | 49 | 43.3 | ....... | 3250 |
| Giovi 1909...... | 990 | 28 | Crank | 224 | 42 | ...... | ....... | .......... |
| Paris-Orleans.... | 250 | 60 | 2.23 | 917 | 49 | 23.5 | 12.00 | 5650 |
| B. & O., 1895... | 270 | 26 | Direct | 146 | 60 | ...... | ....... | .......... |
| B. & O., 1903... | 200 | 35 | 4.26 | 1195 | 42 | ...... | ....... | .......... |
| B. & O. 1910 ... | 275 | 35 | 3.25 | 750 | 50 | 25.0 | 11.50 | 4888 |
| Bernese Alps.... | 1000 | 26 | 3.25 | 530 | 53 | 47.0 | ....... | 6500 |
| Weisental....... | 390 | 46 | Crank | 337 | 47 | 59.0 | ....... | 5200 |

Armature speeds of three-phase railway motors do not exceed the fixed synchronous speed for which the motors are designed.

Armature speeds of single-phase railway motors generally run 10 per cent. higher than that of the direct-current motors.

R. P. M. = M. P. H. x gear ratio x 336 ÷ driver diameter in inches.

The feature which limits the speed of trains is generally the armature, not the track.

Peripheral speeds of armatures, geared to or mounted on driver axles, are generally less than the linear train speed in feet per minute.

10. **Bearings** have been improved by changes in the material, dimensions, and in the method of lubrication.

In Westinghouse practice, for 60-h.p. motors, solid bushings of cast iron are used for armature bearings, and split malleable iron bushings, lined with babbit metal, for axles. Large motors have solid phosphor bronze shells for armatures and split shells for axles, and 1/10 inch of babbit soldered to the bronze. All bearings are lubricated by oil-saturated wool waste as in M. C. B. boxes in steam railroad practice.

In General Electric practice solid brass sleeves, with a thin lining of babbit metal, are used. In case the babbit is melted by overheating, the armature does not rub on the poles. The axle bearings are split. All brasses are cut away so that the oily wool waste comes into contact with large surfaces.

Armature bearings are generally restricted by the available space. After the armature core and winding have been provided for, and the commutator or collector has been added, little room may be left on the shaft for bearings; and it has been customary, since 1897, to place the bearings under the armature windings and also under the commutator. These restrictions do not apply where the motor is mounted above the drivers, and the shaft may extend clear across the locomotive.

Grease was the lubricant in the early days. The change to oil reduced the cost of inspection and maintenance, doubled the life of bearings, and decreased the danger of armatures rubbing on the poles.

Data on bearings of single-phase quill-mounted motors are given in Elec. Ry. Journ., Dec. 12, 1908, p. 1558.

Seats of armature bearings in the field frame are often bored 1/16 inch above the pole center to allow for long wear.

Three-phase motors have very small air gaps, 1/8 to 1/16 inch and in heavy service, long bearings or frequent renewals are required.

11. **Gearing** from 1888 to 1891 was double-reduction, and entailed high maintenance expense. In the early Sprague roads the small motors ran at a normal speed of 1300 to 1500 r. p. m. Four-pole motors, introduced by Wenstrom, Short, and Westinghouse about 1890, allowed single-reduction gearing. The ratio of gearing was soon changed,

from about 12 to 1, to 4 to 1. Pinions of rawhide, sheet steel, bronze, etc., have been replaced by forged steel. The gears are now enclosed in gear cases. Spur gearing has won out in the competition with bevel gearing, worm gearing, hydraulically connected gearing, belts, wire rope, links, chains, etc.

Gears are used at each end of the armature shaft on the freight locomotives of the Baltimore & Ohio, Michigan Central, Great Northern, New Haven, Bernese-Alps, and other railroads.

Gearless motors are used on the passenger locomotives of the New York Central, Baltimore & Ohio, New Haven, etc., the motor being mounted on the axle or on a quill surrounding the axle.

Gear diametrical pitch is 3 teeth per inch for 35- to 75-h.p. motors, 2.5 for 90 to 250-h. p. motors, and 1 3/4 for 315-h.p. freight locomotive motors on the New Haven. The face is 5 to 5 1/4 inches wide.

Gears may be in one piece or split, and of cast steel which may be bolted, keyed, pressed, or shrunk on either the axle or an extension of the wheel hub. Split gears with 4 bolts are used on motors up to 75 h. p.

Gears for heavy railway motors consist of a forged steel rim mounted on a cast steel center. The rim may thus be replaced when worn out.

Pinions are now used which have great strength and uniformity of metal without sacrificing toughness. The steel is reheated after being machined, to gain in wearing qualities. A cast-steel gear ordinarily outlasts three soft pinions, but with improved types the pinion lasts as long as the gear. A great saving is thereby made in the cost of renewals.

Railway motors have notoriously noisy gearing, which is a disturber of the peace, and ordinarily is a nuisance. The vibration and noise indicate wasted energy. The noise comes from rapidly repeated blows of teeth, which cause friction and rapid wear. Gearing in which the teeth are not parallel to the shaft, e. g., helical gears which have sliding contact, should again be tried out. Some improvement is needed.

Gearing is not used advantageously for motors, above 2300-h.p. size for high-speed passenger locomotives in heavy service. Even when lubricated with oil under pressure, the teeth of spur gears are not able to withstand the shock and wear. The bearings wear and soon change the gear teeth diameters and alignment.

12. **Motor axles** of open-hearth steel, with 80,000-pound tensile strength, 20 per cent. elongation, and 25 per cent. reduction in area, have been standardized as follows:

SUMMARY OF AXLE AND GEAR DATA.

| Journal size. | Motor fit. | Gear fit. | Wheel fit. | Distance bet. hubs. | Center of journals. | Maximum wt. | Horse power. | Length of gear seat. | Diameter gear hub. |
|---|---|---|---|---|---|---|---|---|---|
| 3 3/4x7 | 4 1/2 | 5 1/2 | 5 7-16 | 48 | 75 | 15,000 | 45-45 | 6 1/8 | 8 |
| 4 1/4x8 | 5 | 6 | 5 15-16 | 48 | 75 | 19,000 | 45-65 | 6 1/4 | 8 |
| 4 1/4x8 | 5 1/2 | 6 | 5 15-16 | 48 | 75 | 22,000 | 65-100 | 6 1/8 | 8 |
| 5 x9 | 6 | 7 | 6 15-16 | 50 | 76 | 27,000 | 100-150 | 6 1/8 | 9 1/2 |
| 5 x9 | 6 1/2 | 7 | 6 15-16 | 50 | 76 | 31,000 | 150-200 | 6 1/8 | 9 1/2 |
| 5 1/2x10 | 7 | 8 | 7 15-16 | 50 | 77 | 38,000 | 200-250 | 6 1/8 | 10 1/2 |
| 8 x13 | ...... | ...... | 16 15-16 | 55 | 82 | 70,000 | 315- | .......... | 13 |

13. **Suspension of motors** was provided in the first motors by mounting them on the car floor and connecting them to the axles by belts, wire rope, or sprocket chains and often thru a friction clutch. A direct drive

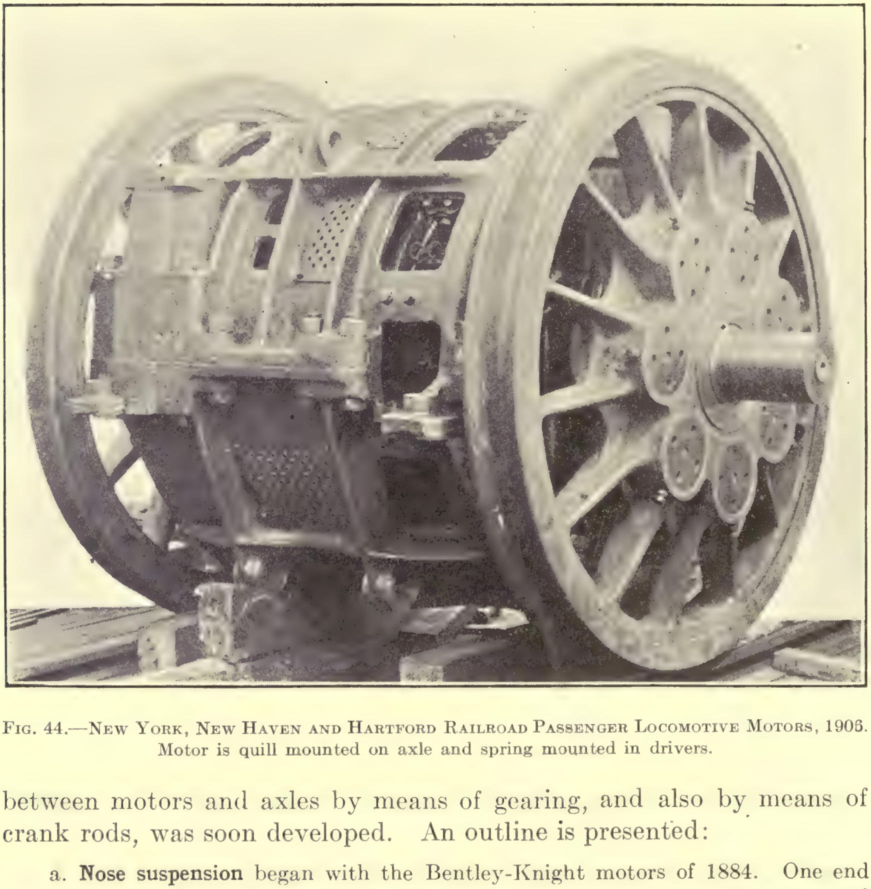


FIG. 44.—NEW YORK, NEW HAVEN AND HARTFORD RAILROAD PASSENGER LOCOMOTIVE MOTORS, 1906. Motor is quill mounted on axle and spring mounted in drivers.

between motors and axles by means of gearing, and also by means of crank rods, was soon developed. An outline is presented:

a. **Nose suspension** began with the Bentley-Knight motors of 1884. One end of the motor and half of the weight were supported directly on the axle bearings, and

the opposite or armature end rested on a cross bar, supported by the side frames of the truck; and in such a way as to provide parallelism between the armature shaft and the axle; *i.e.*, the distance between the centers of the gear pitch circles was fixed. Nose suspension is the simplest and it has superseded all others.

b. **Cradle suspension** was used in the Westinghouse motors of 1890. The entire motor was placed on levers or horizontal bars at each side of the motor, and all of the motor weight was transmitted to the axle and frame indirectly thru springs. Two motors per truck were used, and one motor balanced the other. Each motor formed a lever fulcrumed at the axle. This scheme became obsolete due to the higher first cost and the inaccessibility for repairs.

c. **Side-bar suspension** used on the General Electric No. 800, 1200, and 2000 motors of 1893 removed the dead weight of the motor from the axle. The side bars,

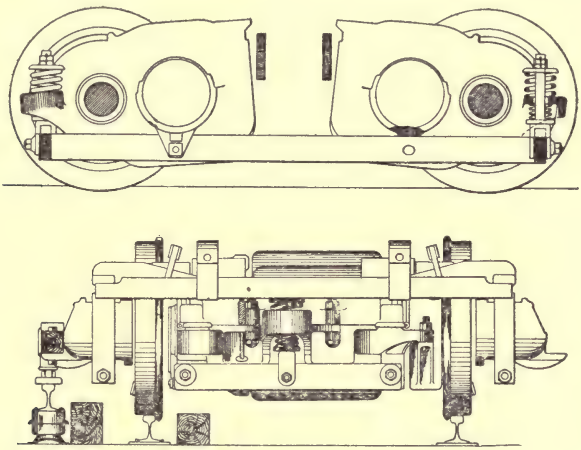


Fig. 45.—Gibbs Cradle Motor Suspension.
As used on Metropolitan Railway, London.

resting entirely on springs, carried the motor. One lug on either side was so placed that the suspension was thru the center of gravity of the motors. There was no weight resting on the axle boxes. In addition to the elimination of pounding, the alignment used was advertised by the General Electric Company as preventing the wear of the boxes and of the gears.

d. **Yoke suspension** was a modification in which the weight of the motor was largely suspended from points in line with the axis of the armature shaft, or practically the center of the weight of the motor. The motor was virtually balanced. General Electric bulletin 4113, of July 28, 1902, stated: "The yoke suspension is especially recommended, as with this suspension the weight of the motor is carried on springs placed on the side frames of the car track," and because the hammer blow of the track is reduced to a minimum.

e. **Walker spring suspension** of 1895, while not in use, deserves a description. The motor, *M*, is suspended entirely on springs at *S* and *T*. Side bars, *Y*, are journaled on the axle, *A*, and at the armature shaft; and they are not connected to the motor frame, and simply keep the pinion and gear in mesh. The nose bar, *C*, supports half of the motor weight, thru springs located on the truck cross bar. Bearings ran longer, the hammering of the track was less, the strains and shock on the pinion

and gears were decreased, the crystallization of wires and insulation was eased, and the total maintenance expense was decreased.

**Nose suspension is an unsatisfactory plan,** because, with one end of the motor mounted rigidly on the two axle bearings, and the other end or nose on the cross bar, there will always be heavy, non-spring-borne weights from axles, drivers, and bearings. The entire weight of the motor should be mounted on suspension springs, which can be placed at the center of gravity, or, better, at the center of rotation of the motor. A special helical spring could be inserted between that part of the motor casting surrounding the axle and the axle bearings—the C. J. Field

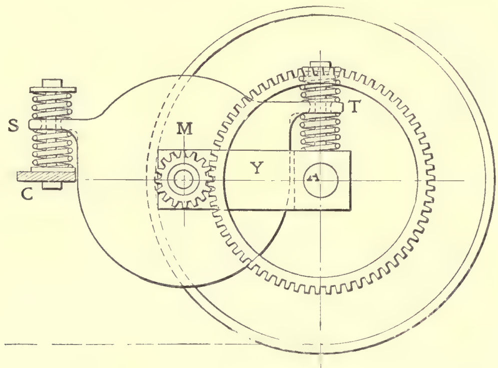



FIG. 46.—DIAGRAM OF WALKER METHOD OF MOTOR SUSPENSION.

scheme, used in 1885. If such suspension springs were used, to ease and attenuate the shocks or track pounding, the present excessive cost of maintenance and renewals at track crossings, switchwork, and curves, and of the motors themselves would be greatly decreased. Track maintenance cost is not higher with electric than with steam power, at least this is not often admitted; but that the cost of maintenance of special work on electric roads is excessive has been definitely proved.

**Suspension of motors for gearless locomotives** involves a field frame independent of the truck frame, or a part thereof, but, in either case, spring-suspended. The armature of gearless locomotive motors at first was placed on the driver axle. Its dead weight, combined with a low center of gravity, was soon found to destroy the crossings, switches, curves, and badly aligned track.

In 1891, the City and South London Railway placed gearless armatures directly on the locomotive axle, but the plan proved to be a failure. In 1895, Baltimore & Ohio gearless locomotives used quill-mounted armatures which were flexibly connected to the driver axle. The field frame was spring-suspended. The improvement was at once noted.

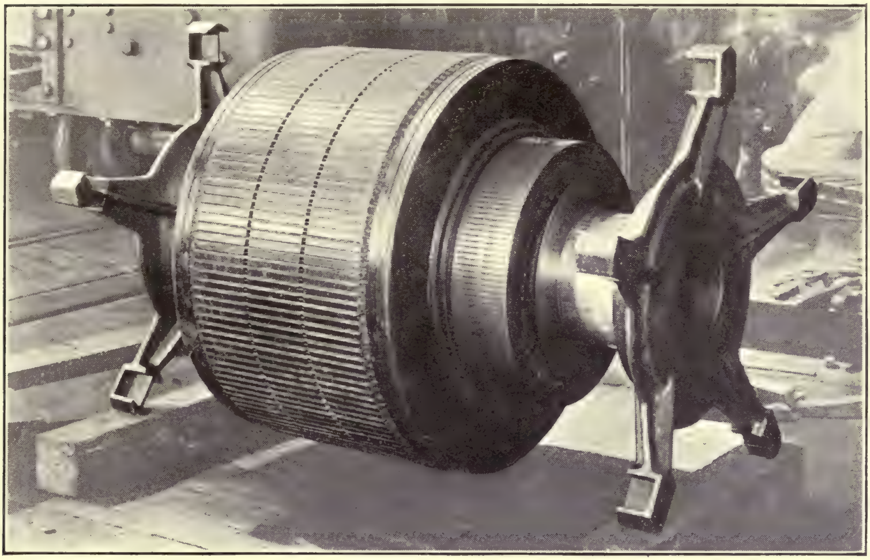


FIG. 47.—BALTIMORE AND OHIO RAILROAD QUILL-MOUNTED MOTOR ARMATURE ON 1895 LOCOMOTIVE.

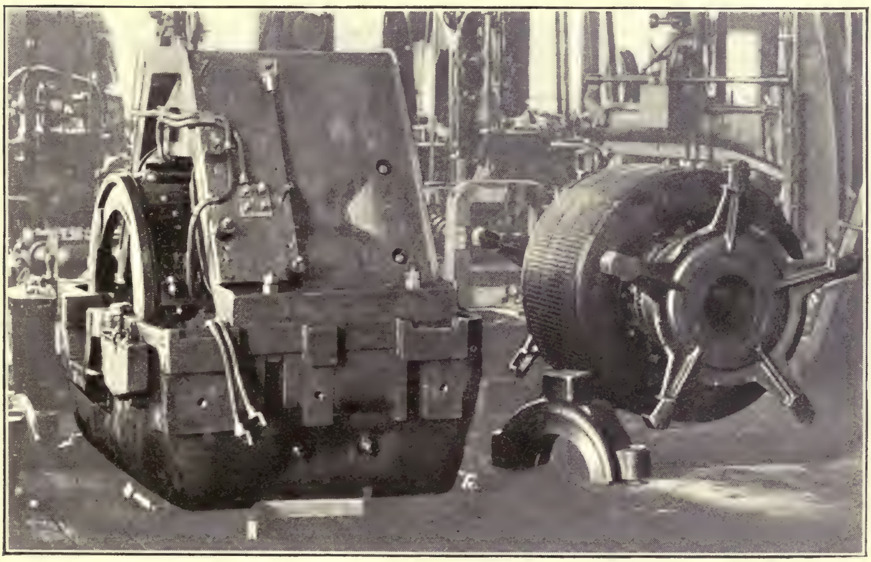


FIG. 48.—BALTIMORE AND OHIO RAILROAD MOTOR FIELD AND ARMATURE ON 1895 LOCOMOTIVES.

New York Central gearless locomotive followed, 10 years later. Motor armatures weighing 7640 pounds each are mounted directly on the axle, and the total dead weight, about 13,000 pounds per axle, is practically the same as on an ordinary steam locomotive; and, tho there are no unbalanced weights or forces, track maintenance expense is high. The weight of the motor frame itself rests on, and forms part of, the locomotive truck frame, and is spring-mounted.

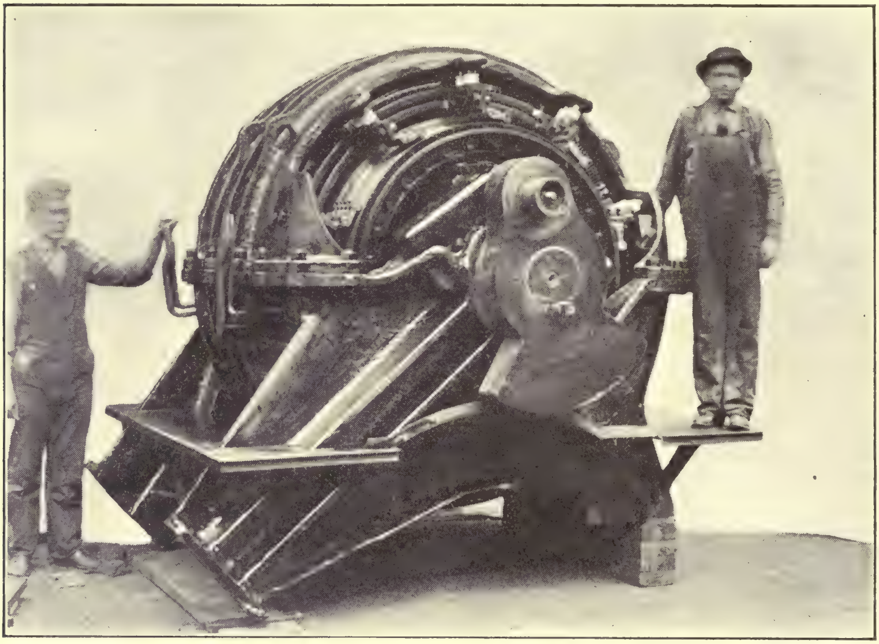


Fig. 49.—Pennsylvania Railroad Motor, 1910.
Direct-current, 650-volt, 1250-h. p. on 157-ton locomotives. The frame is well braced, and the cranks are counter-balanced.

**Quill suspension of armature** involves the mounting of the armature on a hollow motor axle which encircles the driving axle, the inner shaft being held concentric with the outer shaft by means of spiral springs. See technical description of Baltimore & Ohio, New Haven, and Valtellina locomotives, and New Haven motor cars which follow.

Berlin-Zossen motor cars, in the high-speed tests of 1903, used four three-phase, 6-pole, 435-volt induction motors of 250-h. p. each. Siemens and Halske motors, for an 85-ton car, were mounted rigidly upon the driving axles; while A. E. G. motors, under a 99-ton car, were mounted on a hollow shaft, and spring-supported from the driving wheels. The latter plan greatly reduced the track destruction.

**Crank rod locomotive motor suspension** involves motors with cranks on the armature shaft, which transmit the power to the drivers, or to a jack shaft and then to the drivers. The motor is mounted high on the locomotive frames, and is spring-mounted. Mechanical connections of locomotive motors will be treated under "Electric Locomotive Design," and under "Technical Descriptions of Locomotives."

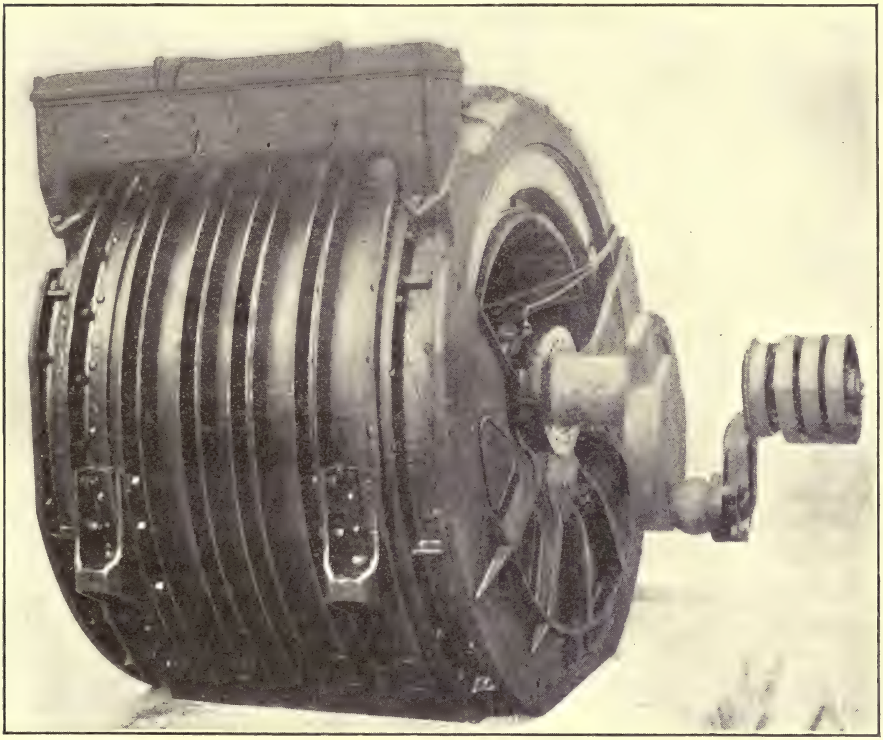


FIG. 50.—VALTELLINA LOCOMOTIVE MOTOR ON ITALIAN STATE RAILWAY, 1906. Three-phase, 3000-volt, 15-cycle, 1200-h. p., 3-speed. Length of body 51 inches, length of shaft 101 inches, diameter of body 74 inches, diameter of collector rings 12 inches.

14. **Trucks** on which motors, cars, and locomotives are mounted could advantageously form the subject of a book. Technical descriptions of trucks for the principal electric locomotives will be given. Catalogs of trucks are valuable for data. See references on trucks.

## SPEED-TORQUE CHARACTERISTICS OF MOTORS.

**Characteristic curves** of a motor are those which show the relation of power to the speed and torque. Speed-torque curves are plotted by using the kilowatts, or amperes at a fixed voltage as a base, and the

corresponding speed and torque in the vertical scale. For comparative purposes, and to note the general form of all curves, the abscissæ and ordinates should be plotted in *per cent.* of rated power, speed, and torque.

One set of such curves is needed for direct-current motors, one for three-phase, one for single-phase series, and one for single-phase repulsion motors. Other curves are used to analyze the relation of power to speed and torque with variable voltage to the motor, or variable resistance in the rotor circuit; and also for different cycles, number of poles, windings, turns on fields and armature, magnetic circuits, air gaps, gear ratio, position of brushes, etc. Still other curves may be used to show the power, speed, and torque characteristics with two or more motors grouped in series-parallel or in concatenated relation; and with resistance or inductance in all or part of the field or rotor circuits. Other curves and combinations will be suggested for special cases.

**Torque of direct-current motors** is proportional to the number of lines of force threading the armature; the number of turns or conductors on the armature; the current in the armature. It is independent of the motor voltage. The lever arm extends thru the crank, gear, and drivers.

**Torque of single-phase motors** is proportional to the square of the impressed voltage, approximately; and the ratio of the reactance of the rotor winding at standstill to its resistance, approximately, and in practice this ratio varies from 6 to 25.

**Torque of three-phase motors** varies directly as the square of the impressed motor voltage; for the flux density of the magnetizing field is relatively small, and the iron is much under-saturated, in order to reduce the iron loss and magnetic leakage. The starting torque is less than the maximum, and thus it is common to increase the voltage across the stator terminals in starting and to reduce it in running by a change at starting from delta to star connection, which changes the voltage in the ratio of 1.00 to 1.73; or to reduce it by means of a booster transformer, or by variable taps on the transformers. The torque is proportional to the magnetization, M; to the slip, S; to the resistance of the rotor, R; and inversely proportional to the total impedance of the motor.

The maximum torque in running, and the current corresponding thereto, are not changed by the resistance in the motor armature. The resistance decreases the speed at which the maximum torque is reached. The pull-out torque of slow-speed three-phase railway motors is usually made from 250 per cent. to 325 per cent. times the continuous torque. It is usually extremely hard to obtain over 300 per cent. for railway motors, altho 400 per cent. is obtained for high-speed stationary motors.

Steinmetz: "Alternating Current Phenomenon," 1st Ed., pp. 220–225.
Dawson: "Electric Traction on Railways," p. 115.
McAllister: "Alternating -current Motor," 3d Ed., Commutator Motors, p. 201.

**Speed** of direct-current motors varies almost directly with the voltage applied to the armature. The speed curve or the counter electromotive force curve is the reciprocal of the magnetization curve. The limits on the ordinates of the speed curves are set first by no saturation of the magnetic circuit, in which case the product of the speed and the current is constant, or at one-half the normal current the speed would be twice the normal speed; and second, by a magnetic field well-saturated, in which case the ordinates, which vary inversely as the magnetization curve, are nearly parallel to the abscissa.

Speed curves of single-phase alternating-current motors are a modification of the continuous-current motor curves. With an alternating-current motor it is necessary to keep the magnetic circuit well below the saturation point of the steel in order to reduce the magnetic losses.

Speed curves of three-phase motors are practically parallel to the axis of abscissa, the variation from no load to full load being less than five per cent.

**Voltage** affects the speed, but not the torque characteristics of direct-current motors; but in single-phase motors, voltage affects the speed and torque as just detailed; and voltage affects the motor capacity as noted under "Rating of Motors."

Voltage affects the torque, but not the speed, of three-phase induction motors, and it affects other characteristics as follows:

Case "A," voltage 10 per cent. above normal:

a. Magnetizing current increases directly as the square of the voltage.

b. Iron loss increased 18 per cent., since the induction in the iron, which varies with the voltage, is 10 per cent. greater.

c. Copper loss in primary is smaller because the current required per h. p. is smaller; copper loss in secondary is only 86 per cent. because of the smaller slip, which for the same h. p. and apparent efficiency varies inversely as the square of the voltage.

d. Efficiency increases slightly, because of smaller losses.

e. Power factor is reduced 2 per cent.

f. Torque in starting and also the pull-out or maximum torque are 21 per cent. greater, on account of the reduced leakage.

Case "B," voltage 10 per cent. below normal:

a. Iron loss is reduced 15 per cent. by the lower flux density.

b. Copper loss in primary is 22 per cent. larger, on account of increased current; copper loss in sceondary is 20 per cent. greater, on account of larger slip.

c. Power factor is increased .7 per cent. by the smaller magnetizing current.

d. Starting torque is about the same, but the pull-out torque is decreased 17 per cent by the larger leakage.

Case "C," voltage 27 per cent. below normal:

a. Starting torque and pull-out torque are about 50 per cent. of normal.

b. Capacity is reduced one-third, because of the excessive temperature rise from the larger copper losses.

**Gearing ratio and driver diameter** affect the torque of the motors. They of course affect the speed of the car or locomotive and the work done. See references on Gearing, page 221.

## CHOICE OF CYCLES.

Engineers favor both 25 and 15 cycles for heavy railway services. The 25-cycle system is in general use in America and in England. See "Electric Systems."

Comparison of 15-cycle with 25-cycle single-phase motors shows there is an increase of from 25 to 40 per cent. in the output of a given motor when a proper increase is made in exciting ampere turns. The gain for large railroad motors is about 30 per cent. It is in the feature of increased induction that the principal gain with lower frequency is found; and the increased induction is obtained with less short-circuiting of armature coils and also with less exciting voltage in proportion to the counter electromotive force, and consequently with higher power-factor.

The limitation in the 25-cycle motor is caused largely by the increase in iron necessary to keep down the inductive element and consequently to secure a reasonable power-factor. Higher efficiency, better commutation, and less weight are obtained in 15-cycle, single-phase motors.

The power-factor of series-compensated, 25-cycle motors of 75 to 250 h.p. is 85 to 90 per cent.; of 15-cycle 75- to 500-h.p. motors is 88 to 93.

A 500-h.p., 15-cycle motor, designed for equally good performance on 25-cycle, produces 360 h.p. at best rating.

"A comparison of 4-motor Westinghouse equipments made up of 75-h. p. motors at 25 cycles, and the same motors adapted for 15 cycles, giving 95-h.p., showed, in the latter case the electrical apparatus per car to be 5 per cent. heavier, the car weight to be 1.6 per cent. heavier, and the h.p. gain to be 26 per cent." Lamme.

Even with increased transformer weight, the 15-cycle equipment, including trucks and frames, is usually lighter.

New York, New Haven & Hartford engineers considered both 15 and 25 cycles for their 1906 passenger locomotive designs. The motors would have been somewhat lighter and the transformers would have been somewhat heavier on 15 cycles. It was found that the 15-cycle locomotive had the advantage of 5.2 per cent. in weight and about 3 per cent. in cost, and was slightly better as to its efficiency and power factor. Based on 1911 conditions and experience in manufacture and design, it is fair to state that 15 cycles would now make a difference of 10 per cent. in weight and 8 per cent. in cost. If the locomotive weight was 30 per cent. of the train weight, it would mean a saving of 3 per cent. in the total weight of the train, but in passenger trains there would be a saving of less than 1 per cent. The 25-cycle system was chosen because standard apparatus had been adapted for this frequency (so far as generators and induction motors were concerned), and because 15-cycle transformers might have cost 40 per cent. more than 25-cycle transformers.

**Results with 25, 30, and 60 cycles** on the same three-phase motors:
Case "A," frequency increased from 25 to 30 cycles.
Starting and pull-out torque reduced 17 per cent.
Efficiency and power-factor improved.
Friction and windage about 45 per cent. higher.
Iron loss decreased 13 per cent.
Copper loss and slip the same.
Leakage is greater.

Case "B," frequency increased from 25 to 60 cycles:
Pull-out torque reduced in the ratio of 3.6 to 1.5.
Starting torque reduced in the ratio of 2.5 to 0.5.
Efficiency slightly decreased.
Iron loss decreased 50 per cent.
Copper loss slightly increased.

Case "C," frequency reduced from 60 to 25 cycles, at rated voltage:

Operation is impossible on account of the high induction required to produce the necessary torque for the same output and 42 per cent. normal speed. At 2.4 times the normal density of the iron, the iron loss is doubled and the magnetizing current will be nearly as great as the energy component. The resulting current makes the copper loss prohibitive.

The torque is proportional to the product of the secondary flux and the secondary current. At 120 per cent. flux, the secondary current should be unchanged The speed varies with the number of cycles.

Abstracted from article by *Werner,* Electric Journal, July, 1906.

**Disadvantages of 25 cycles** compared with 15 cycles:

Cycle change from 60 cycles is decidedly less convenient in design. The ratio of cycle transformation is odd, viz., 12 to 5 in place of 4 to 1.

Field saturation in the motor is 30 per cent. lower and therefore the counter-electromotive force of the armature, the power factor, the output, and the torque are decreased in proportion.

Air gaps must be smaller to raise the field saturation and power factor.

Weight runs up rapidly on larger motors (250 h. p. or over) and is 33 per cent. heavier than that of direct-current motors; while it is only 15 per cent. heavier with 15 cycles.

Capacity, power factor, commutation at time of starting and on overloads, are poorer at 25 cycles.

Cost for given results is higher with 25 cycles.

Speed of large steam turbines must be higher.

**Disadvantages of 15 cycles** compared with 25 cycles:

Field ampere turns for a given induction are increased.

Transformers are more expensive and heavier but this is offset partly by higher power factor and efficiency.

Vibration of 15-cycle railway motors requires special at leads and connections, and often requires riveting in place of soldering; and it causes crystalization of bars and wires.

Other induction motors on transmission lines are more expensive. These include shop motors, cycle changers, transformers, converters, etc.

The low cycles are not so well adapted for electric lighting.

Torque pulsation decreases the output, and this must be dampened by the inertia of springs.

The use of 15 cycles is advantageous for single-phase series motors. The fewer reversals of magnetic flux and induced e. m. f. under the brushes decrease the sparking, heating, and energy loss at the commutator. A motor may be designed, however, which is just as efficient at 25 cycles as at a lower frequency, the weight and cost being the handicap.

**Drawbar pull of locomotive motors** on 12.5 and 25 cycles is noted:

Locomotive No. 9 on the Westinghouse Interworks Railway was tested with 25 cars back of the dynamometer car. The locomotive was started and after the controller was at full position the brakes were applied to the cars only. Both acceleration and deceleration of the train were zero when the tests were recorded. The test at 12.5 cycles was with a line voltage of 3500 and a motor voltage of 160 volts, amperes, 3000, and .60 power-factor. A drawbar pull of 30,000 pounds was obtained before slipping began. The test at 25 cycles was with a line voltage of 6000, and a motor voltage of about 160, amperes 3100, and .57 power-factor. A drawbar pull of 30,000 pounds was obtained. The indications are roughly that the point of slipping for 12.5 cycles is practically the same as that for 25 cycles. Test by L. M. Aspinwall.

**60-cycle locomotives** or motor cars are not used on any railroad. There have been several 50- and 45-cycle experimental equipments and street railways; and 40 cycles are used in the Burgdorf-Thun three-phase interurban. Engineering reasons which prevent the commercial use of higher cycle motors by railroads are listed below:

Losses in copper transmission lines are greater.

Losses in track rail circuits are greater.

Regulation of inductive and control circuits is poorer.

Single-phase motors cannot use the wide range of cycles which is possible with three-phase motors.

Higher cycles compel greatly decreased magnetic induction in the iron of motors by design, and therefore:

Output and torque are proportionately increased.

Higher speeds are required to follow the higher cycles.

Decidedly larger frames are required for motors.

Ratio of output to dimensions is greatly increased.

Drawbar pull per ton is lower with higher cycles.

Air gaps are smaller; or the power factor is lower.

Price per h. p. is higher with 60 cycles.

(The last four reasons govern, in railroad train service.)

## CONTROL OF MOTORS.

Control of trains will be considered under "Motor-Car Trains."

Control of motors involves the starting of the motors, the acceleration

to full speed, definite time limits, uniformity of motion, and economy. The problem varies with the class of service. The time during which power is applied is involved in frequent-stop railway service. The rate of acceleration desired depends upon the service and the length of the run. Uniformity of motion is desirable in rapid transit, but it is necessary when freight trains are started, *i. e.*, the control resistances or voltage variations must be so proportioned that the power is not applied with jerks. Economy is always involved. Magnetization or speed curves of the motor and the speed-torque characteristics are also involved.

Controllers involve various kinds of apparatus, automatic and hand, safety devices, interlocks, etc., all of which cannot be considered.

Designs of motors can be varied to make a permanent change in the speed by a change in air gap, windings, gear ratio, driver diameter, etc.

**Control of direct-current motors** in practice is carried out by means of voltage variations, brought about in three ways:

a. **Resistance** is connected in series with motors or with groups of motors. This resistance is external and is made of cast-iron grids. Liquid resistance, introduced by Field in 1889, is used by Italian State Railways.

b. **Circuit control** is also involved. Resistances and motors may be grouped and cut in and cut out by opening and rearranging circuits, by shunting, or by bridging. The latter scheme prevents sudden rise in voltage and the jerk caused by opening and closing circuits.

c. **Motor grouping,** in which two or more motors are electrically connected in series, then in series and parallel, and later in parallel arrangement, by which each motor receives 25, 50, or 100 per cent. respectively of the line voltage.

**Series-parallel motor control** became common in 1891. The first British patents were issued to Hunter, June 7, 1882. The U. S. patents issued to Hunter, June 26, 1888, embraced:

"The combination of an electrically propelled vehicle having two electric motors, a source of electric supply, and switches for coupling up the motors in series or multiple with the source of supply to vary the speed or power of the motors."

"Series-parallel motor control was in practical use on the Lehigh Valley Avenue Line in Philadelphia in May, 1890." Hopkinson.

Thomson-Houston Electric Company devised a series-parallel control scheme about 1892 with contractors operated mechanically by means of long shafts. So imperfect were the mechanical means of throwing the contractors out and in that it was soon abandoned by the several roads.

A series-parallel controller was perfected in 1893 by Wm. Cooper, F. R. Springer, and the author of this book. It was effective and simple, and one in which all parts, including the rheostat, were enclosed in one box. A semicircular Thomson-Houston rheostat was used, with an 8-inch break of Portland cement insulation across the middle. Magnetic blowouts were also used. As the contact shoe passed across the cement break, the motors were changed from series to parallel by means of ordinary

switch blades. This controller was used from 1893 to 1899, on all Minneapolis and St. Paul cars, and was discarded because of its bulky and out-of-date appearance.

The efficiency of series-parallel control, during the time the cars are accelerating, is about 66 per cent., while the efficiency of ordinary rheostatic control is about 50 per cent. Additional savings arise from the higher motor and line efficiency, and the motor maintenance is also radically reduced.

The accompanying equations show the efficiency of control in direct-current practice.

| Plain Resistance. | Series-parallel. | Series, Series-parallel, Parallel. |
|---|---|---|
| $.50+\frac{I\,R}{2\,E}$ | $.65+\frac{I\,R}{2\,E}$ | $.696+\frac{I\,R}{2\,E}$ |

$I\,R$ is the drop of voltage in the motor and $E$ is the line voltage.

d. **Field control** is obtained in two ways:

By connecting field coils in series and in multiple combinations. This is the commutating field scheme used in the 1883 Edison locomotive and 1888 Sprague motors. Parshall, A. I. E. E., April, 1892.

By shunting part of the field current to reduce the field strength. Large motors on the New Haven and Pennsylvania Railroad locomotives use field control, *i. e.*, normal field and full field. Field control is now utilized with interpole railway motors to increase the efficiency by decreasing rheostatic losses for service requiring frequent acceleration in congested districts and yet to obtain high speeds for long runs. With field control, direct-current locomotive motors now have 8 efficient running notches instead of the 3.

**Control of three-phase motors** is effected in the following ways:

**Resistance** can be inserted in the rotor circuit to vary the torque; but, like placing resistance in the armature circuit of a shunt motor, this is a wasteful plan. The efficiency is lower than when resistance is inserted in direct-current series motor circuits. The starting torque of the three-phase motor is low, and the starting current is excessive unless such resistance is so used. Motors may be run above the synchronous speed, on the down grade, by inserting resistance in the motor, but this also is wasteful. With few stops, the average efficiency for the run may not be materially reduced by inefficient acceleration.

Simplon Tunnel locomotive motors now use squirrel-cage armature, with a resistance about 5 times as high as for ordinary armatures of the same size and type, and, while the motor efficiency is lower at all times, the control is simplified and is somewhat automatic.

An efficient induction motor is substantially a synchronous machine and operates normally with a small slip. If the driving wheels are of unequal size, due to unequal wear, or if two locomotives with wheels of different sizes are coupled together in a train, there will be an unequal distribution of the load. If one driver is 5 per cent.

smaller than another, the motor connected to the larger driver may be operating at double load, while the motor connected to the smaller driver may be doing no work or may even be operating as a generator or as a brake.

Mr. A. H. Armstrong's patent of June 28, 1905, provides means for independently adjusting the torque of several motors, so that the load may be equally distributed at all times, by inserting independent adjustable resistances in series with the secondary windings of each motor.

Giovi locomotives have an arrangement of this nature, but the regulation of the resistance (see description on page 345) is automatic. In either case the resistance loss represents a direct and unavoidable waste.

2. **Pole change** is used to vary the speed of three-phase motors.

Example: *N-S-N-S-N-S-N-S* for 8 poles.
*N N-S S-N N-S S* for 4 poles.

This involves an increase in the complication at windings, particularly so for motor-car trains. When the power is thrown off and the number of poles, and the transformer voltage, are changed by the controller, jerky tractive efforts result, and this may break a train in two. Simplon Tunnel and Giovi locomotives are arranged for two speeds. Some of the Valtellina and latest Simplon locomotives have three and four speeds. See Hellmund: Multi-speed, Squirrel-cage Induction Motors, E. W., Oct. 13, 1910.

**Cascade control** requires the use of two motors having the same or a different number of poles, speeds, and electric windings. The two motors may be on one axle or on different axles. The primary of the first motor is connected to the line, and the secondary or rotor is connected to the primary of the second motor, thru collector rings, while the secondary of the second motor is closed thru adjustable resistances. The synchronous speed of the first motor is the frequency of the supply divided by the number of pairs of poles. Thus, if the cycles are 25 per second and the number of pairs of poles is 2, the synchronous speed of the first motor is 750 r. p. m. The frequency of the supply from the rotor of the first motor to the stator of the second motor may be 25 or any other number of cycles. Assuming that it is the same, then, since the r. p. s. of the first motor are 12.5 and the number of pairs of poles of the second motor is 2, the synchronous speed of the second motor is 6.125 r. p. s., or 375 r. p. m., while running in cascade; and if the motors are on the same shaft or coupled, the speed of both motors will be 375 r. p. m. When the motors are operating in cascade at above half-speed on the down grades, energy is regenerated.

In practice, the auxiliary motor is seldom connected to the line; its function is to use the energy produced by the first motor, and therefore its capacity is 60 to 90 per cent. of the main motor because of the losses thru the main motor, and because the auxiliary motor is or may be out of action the greater part of the time during which the main motor is working. Generally one motor is used alone and then the other. The capacity of the locomotive is the capacity of the larger motor.

For suburban service three motors would be required to provide economical running speeds and a high maximum velocity to obtain a high rate of acceleration.

Cascade control is often used with two motors which have a different number of poles. The motors must be geared to the same sized drivers. If the motors are to be used separately, they may be unequally geared; but this plan introduces complications and is of little practical value.

Cascade control is as efficient as the direct-current series-parallel control, in watt-

hours per ton-mile, or in maximum kilowatts per ton during acceleration. The power-factor is low, 50 to 60 per cent. with half-speed cascade operation. The weight of the three-phase motor equipment with the cascade-single or cascade-parallel plan is 45 to 60 per cent. heavier than direct-current series-parallel equipment.

**General rule** for choice of concatenation or pole change: Where the principal speed is the *high* speed, use concatenation for half speed; where the principal speed is the *low* speed, use the pole-changing plan for double speed.

4. **Voltage control** consists of employing varying potentials on the primary or the stator of the motors. (Giovi Locomotive.)

A high voltage is required in starting to increase the drawbar pull, after which, in running, the voltage can advantageously be reduced. The drawbar pull varies inversely as the *square* of the motor voltage. This control requires that the transformer be carried with the train.

Another control plan is to wind the primary for delta connection for accelerating, and to reconnect it in star for running; this reduces the voltage applied, in the ratio of 1.73 to 1.00. Brown, Boveri Company's Simplon locomotive control embodies a change from an 8-pole, delta-star connection to a 16-pole star connection, and incidentally a change in the voltage per pole in the ratio of 1/2 to 1/1.73, or as 100 to 106.

Great Northern locomotives are controlled by first starting with a Mallet steam locomotive; by varying resistance in the rotor; by varying the voltage to the stator; and by using first two motors and then four.

**Single-phase alternating-current motor control** is obtained by connecting the motor to different taps on a transformer, and thus varying the voltage across the motor. The transformer may have its primary winding connected to the trolley and to the earth, and at the earthed end various taps from the primary may be brought out to give suitable voltages; or taps from the coils of an ordinary secondary winding are connected to the motor. The circuit connections are made by means of contactors energized by a master controller, and the motor runs at the speed corresponding to the connection from the transformer, but without rheostatic loss. The Deri induction motors on European locomotives are controlled by shifting the brushes, from the cab, by means of shafts and levers.

**Efficiency of control schemes, for starting trains,** averages about 66 per cent. for series-parallel control; about 65 per cent. for concatenated three-phase control; and about 75 per cent. for potential control.

**Leonard's control scheme** embodies a single-phase generating and transmitting system, conversion of single-phase current to direct current by a motor-generator on the locomotive, and means for varying the speed by varying the voltage applied to the train motors, from zero to maximum value, without wasteful rheostatic losses.

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*This page is reserved for additional references and notes on Electric Railway Motors for Train Service.*

## CHAPTER VI.

# MOTOR-CAR TRAINS.

### Outline.

**Definition.**
**Development.**
**Motor-car Train Service.**
**Characteristics:**
Flexibility, acceleration rates, high schedule speed, distribution of weight and strains, distribution of motive power, reliability of service, similarity of equipment, independence, safety, capacity.
**Economy of Operation:**
Maintenance of ways, maintenance of equipment, wages, fuel, and power, maintenance per car-mile, total cost per car-mile.
**Cost of Motor-car Equipments.**
**Motor-car Versus Locomotive-hauled Trains.**
**Motor Cars on Trains Versus Single Motor Cars.**
**Arrangement of Motor Cars and Coaches in Trains.**
**Control of Multiple-unit Trains and Locomotives.**
**Technical Descriptions of Motor Cars:**
New York Central & Hudson River; Long Island-Pennsylvania; New York, New Haven & Hartford; Chicago, Lake Shore & South Bend; Valtellina Railway of Italy.
**Installations on Railways. Tables:**
Direct-current, three-phase, single-phase
**Literature.**

## CHAPTER VI.

# MOTOR-CAR TRAINS.

### DEFINITION.

**A motor-car train** is defined as a group of mechanically connected cars equipped with and propelled by electric motors under some or all of the cars of the train. It is generally controlled by an operator, at the head of the train, on the multiple-unit plan of secondary control.

### THE DEVELOPMENT.

The development shows that, since 1885, single-truck motor cars frequently have hauled light trailers for heavy morning and evening street-car service. Interurban and suburban traffic required a double-truck car. At first there was one 50-h. p. motor on each truck; but the weight on the drivers was not sufficient, and the wheels slipped, causing a waste of power and also of time. Four-motor equipments were then adopted, about 1898–1900. The limit in the seating capacity of a suburban car was soon reached, because, when the car was over

FIG. 51.—METROPOLITAN ELEVATED RAILWAY, CHICAGO, MOTOR-CAR TRAIN.

55 feet long it could not be turned on a short radius curve at a street intersection. Two-car trains, a motor and a coach, or two motor cars, operated by one motorman and one conductor for heavy traffic was an economic development which soon followed; but city councils generally prohibited the use of an interurban 2-car train on city streets; and trains

of 2, 3, and 4 cars were compelled to use a private right-of-way, within the city limits.

Locomotive cars, loaded with passengers, hauled trains at Chicago for the Columbian Exposition, in 1893, and for the Metropolitan West Side Elevated Railroad in 1895. The plan was not satisfactory because the locomotives did not have the tractive effort which is required for rapid acceleration. The dead weight was then increased, and the tractive effort and motor capacity were made sufficient for a long train, but were too great for shorter trains. The plan was neither flexible nor

FIG. 52.—BOSTON ELEVATED RAILWAY MOTOR-CAR TRAIN.
Car body length, 60 feet. Seating capacity, 64 passengers. Weight, 54 tons.

economical. The electric locomotive cars for train haulage gave way to the motor-car train when, about 1898, a practical control scheme was perfected.

Economy in wages and power, high-schedule speed, and safety soon required that cars in trains be hauled on a private right-of-way. Clean rails on the right-of-way, and the greatly reduced air resistance per ton when cars ran in trains, decreased the power required, and there was ample tractive effort and speed with only two motors per car. Simplicity and maintenance caused the location of the two motors on one truck. Steam railroads, when they first adopted electric power for suburban train service, simply equipped each passenger coach with two electric motors on one new truck.

### MOTOR-CAR TRAIN SERVICE.

Electric locomotives are used for freight haulage, switching service, thru passenger service, and for passenger terminals.

Motor-car passenger trains are in general use for all elevated railways; underground and tube railways; and for heavy suburban trains on a private right-of-way.

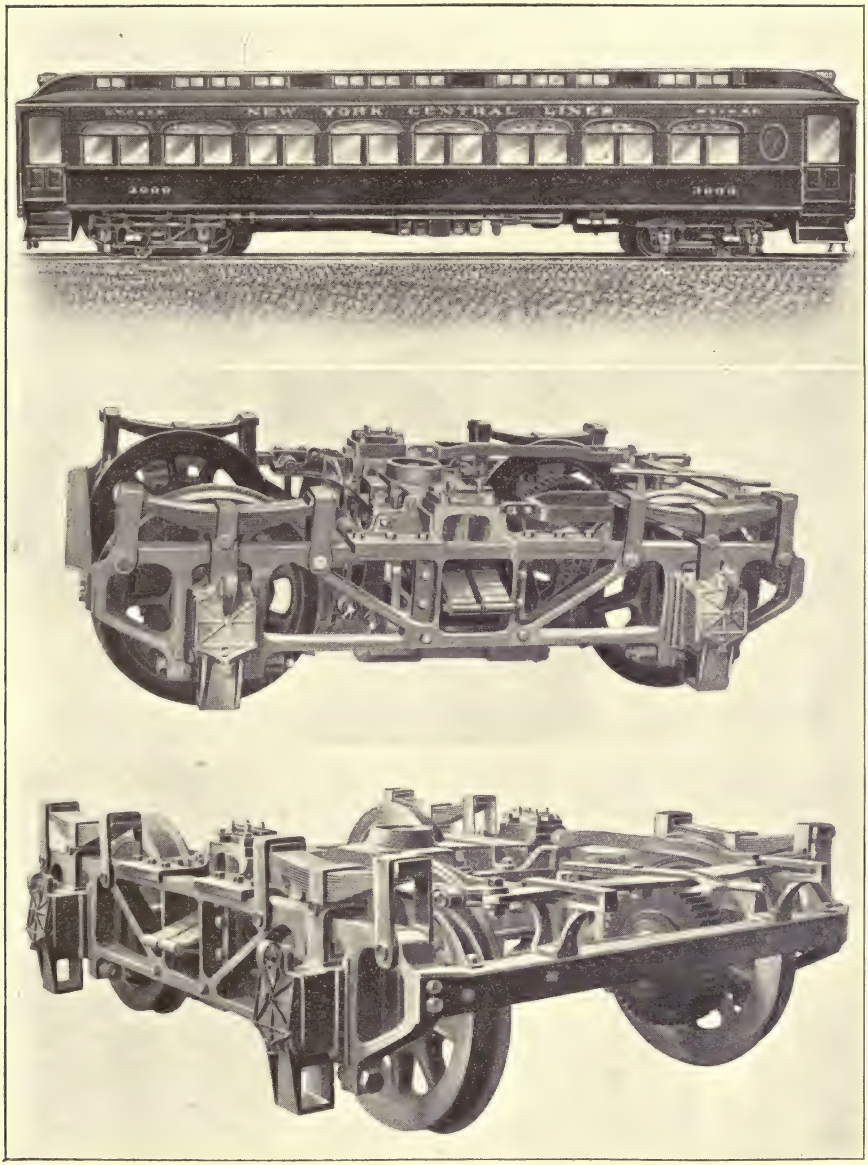


FIG. 53.—NEW YORK CENTRAL & HUDSON RIVER RAILROAD MOTOR-CAR AND TRUCK. Truck weight 8 tons. Wheel base 7 feet. Whoels 36 inches. Swinging bolster supported by double elliptic springs. Truck frame supported from semi-elliptic springs over the journal boxes by spring hangers.

Motor-cars in local freight trains are a recent and a very important commercial development. For example:

North-Eastern Railway of England uses multiple-unit cars for freight service. Each car is 55 feet long, has four 125-h.p. motors, and handles luggage, parcels, and fish. These cars are coupled into either an electric- or steam-driven train.

Paris-Orleans Railway uses heavy motor cars, of the baggage-car type, loaded with supplies and high-grade freight, to haul trains.

FIG. 54.—HUDSON AND MANHATTEN RAILROAD MOTOR CAR.
Length 48 feet; seats 44; weight 35 tons; builder, Pressed Steel Car Company.

Many American railways now employ motor-cars in trains to haul ordinary freight, baggage, building material, and ore. Special motor cars, which carry theatrical scenery, express, milk, fruit, etc., are used in a train, or to haul coaches in local service.

New York Central Railroad for its New York terminal service uses 47 electric locomotives, of 2200 h.p. each, while there are 137 motor cars, of 480 h.p. each. These motor cars haul 63 coaches. Each motor car weighs 53 tons and each coach weighs 41 tons. The motor capacity of each motor-car train exceeds the motor capacity of each locomotive. In 1908 the locomotive mileage was 1,000,000 while the motor-car mileage was 3,500,000. The importance of the motor-car train service is at once recognized.

### CHARACTERISTICS OF MOTOR-CAR TRAINS.

The characteristics of electric motor-car trains are, in part, identical with those for electric locomotives. In addition, other characteristics are those noted in the following ten headings:

1. **Flexibility** is the most important feature, as is shown in operation. Cars are quickly added to or taken from trains to suit the volume of traffic. Single motor cars may be attached for the inbound trip at any

terminal, junction, or branch; on the outbound trip, the train may be split up, and single cars detached for the branch line. Express or passenger cars may even be cut off, or put on the rear end of a train, near any siding or station, without stopping the train, when each car or group of cars has its independent motive power equipment.

This plan to serve the station without delaying the train by a stop, now in practice on many steam passenger trains in England, saves much time, and also the energy required to stop the entire train; but it is somewhat dangerous without an independent source of motive power on the cars which are to be cut on or off.

Flexibility in operation reduces the dead mileage. It allows that concentration of car movement so often desired. Changes are made with dispatch. Motor cars or trains may be added to or taken from the schedule; yet both the speed and economy are maintained. This is not possible with the overloaded or underloaded steam locomotive-hauled train.

2. **Acceleration rates** are rapid and uniform in practice. The acceleration rate used with electric power was one of the first great advantages which attracted the attention of the traveling public. Schedules for train service seldom call for the high rates of acceleration which are possible. American electric roads use rates of 1.2 to 1.6 m.p.h.p.s.

Steam railroad trains cannot gain speed as rapidly as electric motor-car trains, because high rates of acceleration require an enormous weight on drivers, and a large amount of energy. The use of heavy engines, and steam at long cut-offs, in frequent stop service, is expensive.

The reasons for high acceleration of motor-car trains are:

a. Weight of the motor-car train is on the drivers to a great extent. A drawbar pull is provided which is ample, and proportional to the weight and length of the train. The slipping of drivers is avoided. The fastest car movement is possible with the greatest percentage of weight on the drivers; and this may be 4 to 6 times greater than when locomotives are used.

b. Motive power for the train is increased gradually, with the varying length, and number of cars in the train. This feature provides for a constant acceleration rate, yet there is absolute freedom in arranging train intervals and schedules for rapid transit and for changes in traffic.

c. Capacity from the central power station is fully sufficient to meet the requirements for rapid train acceleration.

d. Energy required for propulsion of motor-car trains at a given schedule is least when they are started and stopped at the maximum rate of acceleration and retardation. This is because, first, the maximum speed needed is less with a high acceleration which saves a small amount in train resistance, and, second, the speed at the beginning of braking is less and, consequently, less energy is absorbed and lost

in braking. Economy requires that electric trains making frequent stops be equipped for starting and stopping as rapidly as possible and that train coasting be utilized. This requires the highest rate of acceleration, the greatest drawbar pull per ton of train weight, and that the motive power be placed at intervals thruout the train.

DRAWBAR PULL ON STEAM LOCOMOTIVES AND MOTOR-CAR TRAINS AS USED ON MANHATTAN ELEVATED RAILROAD, NEW YORK, AND IN HEAVY ELECTRIC TRAIN SERVICE IN MANY LOCATIONS.

| No. of cars per train. | Motor cars per train. | Drawbar pull per train elec. | Drawbar pull per train steam. | Weight elec. equip. (tons). | Weight steam locos. (tons). | Weight of train elec. | Weight of train steam. | Drawbar pull per ton elec. | Drawbar pull per ton steam. | Ratio of drawbar pulls per ton. |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 2 | 27,000 | 12,000 | 14 | 24 | 74 | 84 | 365 | 143 | 2.5 |
| 4 | 3 | 40,500 | 12,000 | 21 | 24 | 101 | 104 | 401 | 115 | 3.5 |
| 5 | 4 | 54,000 | 12,000 | 28 | 24 | 128 | 124 | 422 | 97 | 4.3 |
| 6 | 4 | 54,000 | 12,000 | 28 | 24 | 148 | 144 | 366 | 83 | 4.4 |
| 7 | 4 | 54,000 | 12,000 | 28 | 24 | 168 | 164 | 329 | 73 | 4.5 |
| 3 | 2 | 51,000 | 50,000 | 32 | 100 | 137 | 205 | 372 | 244 | 1.5 |
| 4 | 2 | 51,000 | 50,000 | 32 | 100 | 172 | 240 | 296 | 209 | 1.4 |
| 5 | 3 | 76,500 | 50,000 | 48 | 100 | 223 | 275 | 343 | 182 | 1.9 |
| 6 | 4 | 102,000 | 50,000 | 64 | 100 | 274 | 310 | 272 | 161 | 1.7 |
| 7 | 4 | 102,000 | 50,000 | 64 | 100 | 309 | 345 | 330 | 145 | 2.3 |
| 8 | 5 | 127,500 | 50,000 | 90 | 100 | 360 | 370 | 344 | 135 | 2.5 |
| 9 | 5 | 127,500 | 50,000 | 90 | 100 | 395 | 405 | 315 | 124 | 2.5 |

Manhattan elevated coaches weigh only 20 tons. The second set of figures, wherein the coaches weigh 35 tons, should be use for ordinary train service.

The difference in weight is small except when there are few cars per train.

When unusually rapid acceleration is required, as on Hudson and Manhattan R. R., all of the cars are motor cars. If few stops are to be made, three motor cars are sufficient for a 5- or 6-car train.

3. **High schedule speed** is practical because there is great drawbar pull for rapid acceleration, and a central station power supply. Adequate service is provided for the ordinary, congested, morning and evening traffic, with frequent stops in which a high schedule speed is absolutely essential. Rapid acceleration to full speed in the minimum time allows a lower maximum speed.

**High speeds,** 75 miles per hour or more, are hard to attain with trains hauled by steam locomotives. Berlin-Zossen electric passenger cars repeatedly attained a speed of 125 m. p. h., an interesting record. The high speed which is possible with electric power exceeds that which can be obtained safely from a locomotive having reciprocating effort and unbalanced motion.

"The power increases at a higher ratio than the square of the speed at higher speeds, and it would be necessary to use steam locomotives of such large dimensions that a large part of the motive power would be used in driving them alone, and thus the service could not be commercially practicable. The steam locomotive has therefore not been considered in these projects for the high-speed railway, and electricity has been provided as motive power for the hauling of trains."

4. **Distribution of weight** of the train on the rail is excellent. This decreases the intensity of pressure and of strains by distributing them along the roadbed, bridge, or elevated structure. Distributed weights and strains decrease the first cost of the road and the cost of track maintenance, and increase the safety in operation. Total weights of motor-car and steam locomotive hauled trains were compared in Chapter III; and motor-car and electric locomotive hauled trains in the last table.

5. **Distribution of motive power** thruout the train is ideal, in practical operation. Power is not concentrated in one or two locomotives at the head of the train. Strains transmitted to the supporting structures, along the car bodies, and thru the couplers are reduced. Capacity in transportation can thus be a maximum.

6. **Reliability of motor-car service** must be admitted. The duplication of motors provides for a reserve in case of accident to individual motors. Controllers are complicated, but work remarkably well in practice.

Interborough Rapid Transit Company, of New York City, operated 119 miles of elevated track and 80 miles of subway track, and in 1907 maintained 1439 motor cars and 994 trailers. It was necessary for each car to run on an average 4000 miles per month, and to make 10,000 stops and starts during that time. Under these conditions, the average car mileage per delay due to electrical and mechanical causes was 32,642 in the case of the subway and 41,792 in the case of the elevated road.

New York Central electrical zone records for 1908 showed that the multiple-unit cars traversed 3,500,000 miles with train delays of 830 minutes, about equally divided between electrical and mechanical causes. Katte, to New York Railroad Club, March 19, 1909.

Hudson and Manhattan Railroad trains between New York and New Jersey, in March, 1911, ran 112,000 car-miles per delay of 1 minute. The service is severe, with a recognized disadvantage of underground operation, a headway during rush hours of 90 seconds, more passengers per car-mile than any rapid-transit line, numerous sharp curves, and grades from 2 to 4 1/2 per cent. The monthly car mileage exceeds 600,000.

Performances of this kind are unparalleled in steam transportation, and they deserve consideration and study.

7. **Similarity and duplication in equipment** is an asset from an investment and from an operating standpoint.

8. **Independence** of each car is a most valuable physical advantage, to be utilized in varying the schedule, to cut out the dead mileage, to split at junctions, etc.

9. **Safety** is assured in the operation of motor-car trains. The subject as detailed under "Characteristics of Electric Locomotives," follows:

FIG. 55.—WEST JERSEY & SEASHORE RAILROAD MOTOR-CAR TRAIN.
Altantic City-Camden, New Jersey.
Direct-current, third-rail equipment, 1906.

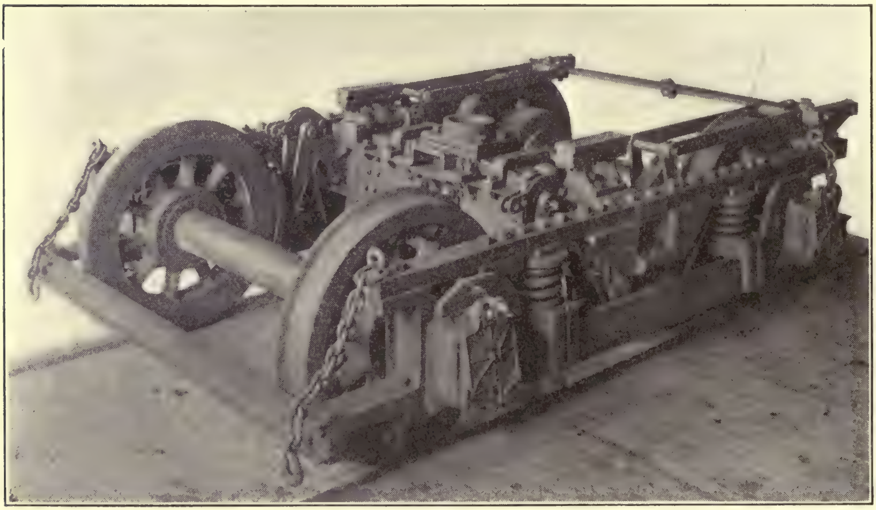

FIG. 56.—MOTOR-CAR TRUCK USED BY WEST JERSEY & SEASHORE RAILROAD.
Baldwin truck and General Electric 240-h. p. motors.

a. Design of electric motors decreases strains and pounding.
b. Control circuits prevent accidents.
c. Automatic devices on controller safeguard operation.

d. Speed is increased with safety, by the design of motors. Speed may be limited by design or by control devices.
e. Wheel bases which are long and rigid are avoided.

FIG. 57.—WEST SHORE RAILROAD THREE-CAR TRAIN.
Third-rail road, Syracuse to Utica, N. Y.

f. Tests of equipment are facilitated and are rigid.
g. Regeneration of energy in braking prevents accidents.
h. Air brakes are used in tunnels with safety.

FIG. 58.—PITTSBURG, HARMONY, BUTLER & NEW CASTLE TWO-CAR TRAIN.
1200-volt, direct-current railway.

i. Boilers and reciprocating mechanism are avoided.
j. Exhaust steam and smoke are absent.
k. Fire risk to property is decreased.

l. Enginemen are not distracted with other duties.
m. Meters are used to assist in intelligent operation.
n. Weights are not excessive, and are distributed.

Fig. 59.—Maryland Electric Railway. Baltimore and Annapolis Short Line Motor Car. Single-phase 6600-volt railway.

Fig. 60.—Pittsburg and Butler Motor-car Train. Single-phase 6600-volt railway.

A recent practice in motor-car train service is to place a steel baggage car at the head of each passenger train, so that, in case of collision or derailment, the safety to life will be increased.

10. **Capacity** is a prime characteristic of motor-car trains. The subject was treated in Chapter III, "Advantages of Electric Traction." In addition:

FIG. 61.—ERIE RAILROAD. ROCHESTER DIVISION MOTOR-CAR TRAIN.

FIG. 62.—ROCK ISLAND SOUTHERN MOTOR-CAR TRAIN.

Motive power from the central station is available for the ordinary 6- to 10-car train, the power supplied to which is usually larger than that required by the electric locomotive hauled train. Rapid acceleration, which is so often desired, requires abundant motive power.

Terminal capacity is increased by more efficient train movements, absence of the locomotive turning, and rapid acceleration.

### ECONOMY OF OPERATION.

Economy in transportation is of vital importance. It requires ability to furnish capacity, speed, and unexcelled service; to induce traffic, to prevent complaint, to get business in competition, and to hold it, are all advantageous, because business should be developed on a large scale to be most profitable.

FIG. 63.—SALT LAKE AND ODGEN RAILWAY MOTOR-CAR TRAIN.

Economy of operation with electric motor-car trains is higher than with any other scheme of operation yet offered in railroading. This has been proved by results, and by use of such trains for the bulk of the suburban passenger train service from many large cities.

The reasons for economy are grouped as follows:

1. **Maintenance of ways and structures** is less because of the distribution of train weight, stresses, and motive power.

2. **Maintenance of equipment** is a minimum because of simplicity, lower cost of inspection, higher mileage, and higher rates of acceleration which allow a lower maximum speed.

For comparison,—New York Subway in 1909 had 735 motor cars each equipped with two 240-h.p. motors, or an equipment of 350,000 h.p. This would be equivalent to about 350 locomotives of 1000 h.p. each. Compare the small Interborough repair shop in use at the end of its line with the tools, machinery and the men, the round houses, shop

equipment, washing plants, cinder pits, turn tables, etc., which would be required for 350 steam locomotives.

Terminal charges would cost about $1.50 per steam locomotive, as compared with 22 cents per motor car. Maintenance and repairs in the two cases would show a cost from $2250 to $2750 per year per steam locomotive, and from $100 to $120 per year for a 400-h.p. motor-car equipment; or, including the steam and electric power plant, the total cost per motor-car is from $225 to $275 per car per year.

Motor inspection and overhaul are made after every 1200 to 1500 miles.

Manhattan Elevated Railroad records show that while the road was operated by steam until 1906, the cost of maintenance was 4.2 cents per train-mile, while with electric traction the cost is 2.1 cents per train-mile. Its data also show,—for steam operation a cost of .39 cent per car-mile; for electric operation a cost of .28 cent per car-mile. Had the weight and speed not been increased with electric traction, the results would have been .20 cent per car-mile. Stillwell.

Twin City Rapid Transit Company, which operates the electric railway and interurban lines in and between Minneapolis, St. Paul, Stillwater, and Minnetonka, 378 miles of track, with eight hundred 23-ton 48-foot motor-cars, and 21 freight motor cars, each equipped with 240- to 300-h.p. per car, shows the following:

> "With a passenger car mileage of over 2,000,000 miles per month, we are doing very little rewinding of either armatures or fields. We are not having any trouble on account of motors overheating. During the year 1909, we have not averaged two men working as winders per day and a great many days we have not had a single man working on armature windings." J. W. Smith, Master Mechanic. E. T. W., VI, 32.

3. **Wages** are saved in the operation of trains for many reasons.

The rate paid per hour is lower because the work is simple, more automatic, and less dangerous. The rate now paid by the New York Central, 38.5 cents per hour, is the same for handling either electric or steam trains; yet on less important traffic the wages are reduced.

One engineman or motorman is used in place of two men, to hand e a train of 4 to 12 motor cars.

Heavier trains are hauled with electric power. The increased weight and length make a saving in the cost of wages per ton-mile, per train-mile, and per passenger-mile.

Faster tra'ns are hau'ed with the available capacity, which reduces the trainmen's wages per passenger carried, or per ton of freight hauled. See table on "Schedule Speed of Trains, Increased by Electric Traction," in Chapter XI.

Maintenance and inspection are greatly decreased. These and other reasons have been detailed in Chapter III under "Wages."

4. **Fuel and power** are saved in operation as is explained in Chapters III and VI. Four reasons for the saving are, briefly,

Power is produced, and utilized efficiently.

Dead weight is reduced.

Fuel is used advantageously, and the total cost of fuel is reduced fully 50 per cent. in ordinary cases.

Water power is often available to reduce the costs.

FIG. 64.—SPOKANE AND INLAND EMPIRE RAILROAD MOTOR-CAR TRAIN.
The 6600-volt, 25-cycle system. Four 100-h.p. motors per 42-ton motor-car.


FIG. 65.—LONDON, BRIGHTON AND SOUTH COAST RAILWAY MOTOR-CAR TRAIN.
The 6600-volt, 25-cycle, single-phase system. Four 115-h. p. motors per motor car; two 55-ton motor cars ond one 35-ton coach per three-car train. Four 175-h. p. motors per motor car; two 60-ton motor cars and two 35-ton coaches per four-car train.

5. **Cost of maintenance and total cost of operation** must be placed on a comparable basis, *i. e.*, per car-mile, ton-mile, seat-mile, etc., rather than per train-mile. Comparisons with similar tables on the maintenance cost of electric locomotives are valuable where the two classes of service

are worked together. Operating cost for motor-car trains is presented quantitatively in the tables which follow.

MAINTENANCE EXPENSE OF MOTORS PER CAR-MILE.

| Name of railway. | Elec. equip. | Motor car. | Reference or authority. |
|---|---|---|---|
| Boston Elevated | | 1.84¢ | Mass. R. R. Commission. |
| Boston & Worcester | | 3.00 | Annual report. |
| Manhattan Elevated | 0.25¢ | 2.14 | |
| New York Subway | .25 | 1.32 | E. R. J., March 28, 1908. |
| Brooklyn Rapid Transit, Elev. | .16 | 1.63 | |
| New York Central | | 1.00 | |
| Long Island R. R. | .76 | | Gibbs, 1910. |
| West Jersey & Seashore | .66 | 1.01 | Wood, 1911. |
| Philadelphia Rapid Transit | | 1.78 | Annual Report, 1909. |
| Washington, Balt. & Annapolis | .24 | | E. R. J., May, 1911, p. 913. |
| Lackawanna & Wyoming Valley | .84 | | |
| Wilkes-Barre & Hazelton | .39 | 1.78 | Annual Report, 1909. |
| Montreal Terminal Ry | | 2.20 | Annual Report, 1909. |
| Hudson Valley | | 2.00 | Annual Report, 1909. |
| Fonda, Johnstown & Gloversville | | 2.90 | Annual Report, 1909. |
| Buffalo & Lockport | .79 | | |
| Michigan United | | 1.00 | Annual Report, 1909. |
| Indianapolis & Cincinnati | .75 | | Renshaw, June, 1910. |
| Sixty street rys | | 2.17 | Mass. R. R. Com., 1908. |
| Twenty heavy electric rys | | 1.49 | Street, to New England |
| Twenty electric heavy ry. power plants | | 2.29 | R. R. Club, 1904. |
| Scioto Valley Traction | | 1.91 | Annual Report, 1909. |
| Aurora, Elgin & Chicago | | 1.38 | Ill. R. R. Com., 1908. |
| Chicago & Oak Park | | 1.02 | Ill. R. R. Com., 1908. |
| Metropolitan Elevated | | 1.55 | Ill. R. R. Com., 1908. |
| Northwestern Elevated | | 1.90 | Ill. R. R. Com., 1908. |
| South Side Elevated | | 1.41 | Ill. R. R. Com., 1908. |
| Minneapolis & St. Paul Suburban | | 1.40 | Minn. R. R. Com., 1909. |
| Spokane & Inland | | 3.08 | Annual Report, 1909. |
| Central California Traction, 1200 volts | | 2.01 | E. R. J., Oct. 2, 1909. |
| Havana Electric Ry | | 2.84 | Annual Report, 1909. |
| Ordinary electric locomotive per mile | | 5.00 | See data, Chapter VII. |
| Ordinary steam locomotive per mile | | 8.00 | See data, Chapter II. |

Some of the reports on electric equipment are per electric-car mile, and apparently others are per motor-car mile.

New York Subway motor cars are overhauled every 65,000 miles. Inspection every 1200 miles costs 0.5 cent per car-mile.

Long Island Railroad motor cars are overhauled every 60,000 car-miles. Inspection every 100 car-miles costs 0.61 cent per car-mile. The cost of the same item for a steam train is 1.14 cents.

MAINTENANCE EXPENSE OF ELECTRIC CARS PER CAR-MILE.

| Name of railroad. | No. of motor cars. | No. of electric cars. | Electric car repairs and renewals. | Electric car mileage. | Cost per car-mile. Cents. |
|---|---|---|---|---|---|
| New York Central | 137 | 200 | $33,897 | 3,500,000 | 0.96 |
| Pennsylvania-Long Island | 132 | 219 | 65,632 | 4,945,719 | 1.34 |
| West Jersey & Seashore | 93 | 93 | ........... | 4,552,531 | 1.01 |
| New York Subway, 1907 | 837 | ........ | ........... | 44,000,000 | ......... |
| Paris Subway, 1907 | 951 | ........ | ........... | 34,000,000 | ......... |
| Erie R. R. (1909) | 6 | 12 | 11,286 | 304,666 | 3.70 |
| Norfolk & Southern | 18 | 37 | 6,838 | ........... | ......... |
| Boston & Maine | 12 | 12 | 14,660 | 746,857 | 1.90 |
| Wilkes-Barre & Hazleton | 6 | 7 | 10,877 | 310,647 | 3.50 |
| Lackawanna & Wyoming Val. | 35 | 36 | 74,375 | ........... | ......... |
| Scioto Valley | 17 | 17 | 23,770 | 1,164,821 | 2.04 |
| Northwestern Elevated | 288 | 388 | 149,593 | 12,550,306 | 1.20 |
| Chicago & Milwaukee | 54 | 78 | 39,311 | 2,878,864 | 1.38 |
| Rock Island Southern | 8 | ........ | ........... | 232,099 | 1.32 |
| Waterloo, Cedar F. & Northern | ....... | ........ | 8,488 | 550,897 | 1.54 |
| Colorado & Southern | 10 | 20 | 2,840 | ........... | ......... |
| Spokane & Inland | 25 | 35 | 118,855 | 3,157,401 | 2.66 |
| London Underground | 383 | 908 | ........... | ........... | 1.00 |

Data for the first roads listed are from special I. S. C. C. reports, for 1908, 1909 or 1910; other data are from annual reports of the railroad companies, and from other sources.

Cost of maintenance does not include depreciation or superintendence. Maintenance expense varies with the number of cars operated, and with the number of stops per mile.

TOTAL OPERATING EXPENSE OF MOTOR-CAR TRAINS PER CAR-MILE.

Includes Maintenance and Repairs, and all Items Except Fixed Charges.

| Name of railway. | Cost per car-mile electric. | Cost per car-mile steam. | Reference, notes or authority. |
|---|---|---|---|
| Boston Elevated | $.1850 | .......... | Annual Report. |
| The Connecticut Company | .1556 | .......... | Annual Report. |
| Manhattan Elevated | .1005 | .3900 | Public Service Com. |
| Interborough Subway | .0974 | .......... | ........................ |
| Brooklyn Rapid Transit, Ele. | .1607 | .......... | Annual Reports. |
| New York Central | .1858 | .......... | E. R. J., Jan. 14,1911, p. 69. |
| Hudson & Manhattan | .1653 | .......... | Annual Report, 1910. |
| Long Island R. R | .1780 | .2795 | Gibbs. 144-ton trains, 1908. |
| West Jersey & Seashore | .2046 | .2230 | Gibbs. 163-ton trains, 1908. |
| | .1819 | .2500 | Wood, 166-ton train, 1910. |
| Wilkes-Barre & Hazelton | .1120 | .......... | Annual Report, 1909. |
| Wash., Balt. & Annapolis | .1900 | .......... | E. R. J., May, 1911, p. 913. |
| Erie R. R | .1800 | .......... | Lyford. A. I. E. E., 1908. |
| Michigan United | .1190 | .......... | Annual Report, 1909. |
| Indiana interurbans | .1580 | .......... | Indiana R. R. Com., 1908. |
| Lake Shore Electric | .1548 | .......... | Annual Report, 1910. |
| Fifty-five electric roads | .1320 | .......... | Average. |
| Scioto Valley Traction | .1660 | .......... | Annual Report, 1909. |
| Aurora, Elgin & Chicago | .1510 | .......... | Illinois R. R. Com., 1908. |
| Chicago & Oak Park Elevated | .1100 | .......... | Illinois R. R. Com., 1908. |
| Metropolitan Elevated, Chicago | .1070 | .......... | Illinois R. R. Com., 1908. |
| Northwestern Elevated, Chicago | .0910 | .......... | Illinois R. R. Com., 1908. |
| South Side Elevated | .1100 | .1060 | Brinckerhoff. See p. 104. |
| Lake Street Elevated | .1170 | .1174 | Illinois R. R. Com., 1909. |
| Rock Island Southern | .1360 | .......... | Illinois R. R. Com., 1909. |
| Illinois Traction Company | .1970 | .......... | Illinois R. R. Com., 1908. |
| Milwaukee Northern | .1610 | .......... | Wisconsin R.R. Com., 1910. |
| Waterloo, Cedar F. & Northern | .1980 | .......... | Annual Report, 1909. |
| Ft. Dodge, Des M. & So | .2067 | .......... | Iowa R. R. Com., 1909. |
| Minneapolis & St. Paul Suburb. | .1750 | .......... | Minn. R. R. Com., 1910. |
| Spokane & Inland | .2670 | .......... | Annual Report, 1909. |
| Central California Traction | .1610 | .......... | E. R. J., Oct. 2, 1909. |
| Mersey Ry., England | .1260 | .2730 | Shaw, B.I.C.E., Nov., 1909. |
| Underground Electric, London | .1950 | .......... | Annual report, 1908. |

Long Island did not make a radical change in length of trains when a simple substitution was made from steam to electric power.

West Jersey & Seashore under steam operation ran twice as many cars per train, for express service, usually with a few stops; electric trains are shorter, 3 to 4 cars, and make frequent stops. The showing is, therefore, the more remarkable, since it costs decidedly more to run a short train with many stops than a thru train.

The expenses include power, maintenance of power plant, transmission lines, substations, contact lines, cars and motors, wages of all operators, traffic and general expense, and all operating expenses of the railway.

The cost per car-mile with electric traction should be high because of the larger number of stops per mile, higher schedule speed, and greater power per train.

COST OF MOTOR CARS WITH MOTOR EQUIPMENT.

| Name of railroad. | Year noted. | No. of seats. | Length of car. | Wt. tons. | Motors & h.p. of motor. | Kind of current. | Estimated cost. | Notes. |
|---|---|---|---|---|---|---|---|---|
| New Haven, Boston | 1911 | ...... | ...... | ...... | 4–150 | Alternate.. | $30,000 | Steel. |
| Boston & Albany... | 1911 | ...... | ...... | ...... | 2–240 | Direct .... | 17,829 | Steel. |
| Boston & Eastern... | 1910 | ...... | 55 ft. | ...... | 4–200 | Direct..... | 16,850 | ...... |
| Boston Elevated.... | 1905 | ...... | ...... | 33 | 2–165 | Direct..... | ...... | ...... |
| New Haven........ | 1909 | 76 | 70 | 87 | 4–150 | Alternate.. | ...... | ...... |
| New York Central... | 1906 | 68 | 60 | 54 | 2–240 | Direct..... | ...... | Steel. |
| West Jersey & S. S. | 1906 | 58 | 56 | 48 | 2–240 | Direct..... | 12,214 | Wood. |
| | 1911 | ...... | ...... | 52 | 2–240 | Direct..... | 19,500 | Steel. |
| Long Island........ | 1910 | 52 | 51 | 41 | 2–200 | Direct..... | ...... | Steel. |
| Pennsylvania....... | 1909 | 68 | 67 | 75 | 2–210 | Direct..... | 18,500 | Steel. |
| Interborough ...... | 1911 | 500 | 510 | 350 | 14–240 | Direct..... | 110,000 | Steel. |

Cost of converting a 38-ton steam coach to a motor car, about $3800.

Cost of cars with 4-motor, 125-h.p. equipment, and multiple-unit control, direct current $19,000; and alternating current $24,500; ditto 50-h.p., direct-current, for interurban service, $6000; one truck, $1000. See cost of steam cars, Ry. Age Gazette, Sept. 30, 1910, p. 578.

## MOTOR-CAR VERSUS LOCOMOTIVE-HAULED TRAINS.

Comparisons of motor-car trains and locomotive hauled trains show:

**Drawbar pull** of electric motor-car trains has been shown to be from 1.5 to 4.5 times greater than steam locomotive-hauled trains.

**Weight** of a motor-car train is less than that of an electric locomotive hauled train. The difference amounts to about 44 per cent. for a 2-car train; 30 per cent. for a 3-car train; and down to 12 per cent. for 6-, 8-, and 10-car trains. This is shown by the examples below:

COMPARISON OF TRAIN WEIGHT, ELECTRIC AND STEAM.

Based on the same Tractive Effort and Number of Seats.

| Service. | Light suburban. | | Heavy railway. | |
|---|---|---|---|---|
| Motive power. | Electric locomotive. | Motor-car trains. | Steam locomotive. | Motor-car trains. |
| Wt. of loco, tons. | 92 | 0 | 165 | 0 |
| Wt. of cars, tons. | 3@36, 108 | 3@46, 138 | 6@60, 360 | 6@75, 450 |
| Wt. total, tons... | 200 | 138 | 525 | 450 |
| Saving with...... | 3 cars. | 31% | 6 cars. | 14% |
| Saving with...... | 2 cars. | 44% | 7 cars. | 10% |

COMPARISON OF TRAIN WEIGHTS, ELECTRIC AND STEAM.
Based on Ordinary Suburban Service.

| New York Central & Hudson River R. R. | Steam locomotive service. | Motor-car train service. |
|---|---|---|
| Wt. of steam locomotives, tons. . | 138 | 0 |
| Wt. of motor cars, tons . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | | 4–216 |
| Wt. of coaches, tons . . . . . . . . . . . | 6–200 | 2– 82 |
| Wt. of passengers, tons. . . . . . . . . | 12 | 12 |
| Wt. total, tons. . . . . . . . . . . . . . . . . | 350 | 310 |

Weight was reduced 40 tons per train, for the same number of seats. S. R. J., Nov. 4, 1905, p. 837.

Weight of motor cars is increased gradually and in proportion to the train length. Fixed dead weight of locomotive and tender are cut out, and an economy is effected in the ton-mileage. North-Eastern Railway of England, which electrified its steam road in 1904, has increased its train-mileage 100 per cent., yet its ton-mileage has not been increased.

Weight distribution is excellent. Shearing and deflecting strains on structures are reduced.

**Flexibility** of motor cars decreases the cost of shunting or switching. Space is saved in restricted yards.

**Acceleration** for any train combination is the most rapid. "Equal acceleration, speed, and equality of work from each motor car whatever the number of cars in a train." Sprague.

**Lowest maximum speed** is obtained with a given schedule speed.

**Highest schedule speed** is obtained with a given maximum speed.

**Fuel** expenditure per car-mile is lowest with motor cars.

**Cost of operation** is also lowest with the motor-car train.

Unless it is practical to operate trains with a fixed number of coaches, the motor-car train equipment has all the major operating advantages.

**Investment** for motor car trains is greater; but is compensated by improved facilities for handling traffic and increased gross and net earnings.

See "Advantages of Locomotives over Motor-car Trains," Chapter VII.

## MOTOR CARS IN TRAINS VERSUS SINGLE MOTOR CARS.

The proper choice for a given service, which may be supplied either by 2- or 3-car trains, or by more frequent service with single cars, is determined by gross earnings or traffic productivity and operating expenses.

Traffic may be attracted by greater comfort or better accomodations. For example, seats may be offered in place of straps; or several cars per train to provide smoother riding qualities.

Economy of operation is higher with trains than with single cars, per seat-mile and per ton-mile because:

Wages are saved. The saving increases with the train length.

Power consumption is greatly decreased because there is less friction per ton. See "Power Required for Trains."

Maintenance is less per ton-mile because less power and fewer motors are required for train service than for single cars.

### ARRANGEMENT OF MOTOR CARS AND COACHES IN TRAINS.

Arrangement of motor cars and coaches in trains is detailed in the tabular data at the end of this chapter. One example is cited:

Long Island Railroad has 23 different types of local and express train runs, over 13 different routes. The distance between stops for local trains varies between 1.6 and 1.0 miles; and for express trains, the distance between stops is as much as 9.6 miles. On an average there are 3 to 4 cars per train.

Motors on 136 motor cars consist of two 200-h. p. direct-current units. A gear ratio of 2.32 is used. Weight of motor car is 38 to 41 tons, and coaches weigh 31 tons.

MOTOR CARS PER COACH IN LONG ISLAND R. R. TRAINS.

| Number of cars. | Local service. | Express service. |
|---|---|---|
| Two-car train | Two motor cars | One motor car. |
| | No coaches | One coach. |
| Three-car train | Two motor cars | Two motor cars. |
| | One coach | One coach. |
| Four-car train | Three motor cars | Two motor cars. |
| | One coach. | Two coaches. |
| Five-car train | Three motor cars | Three motor cars. |
| | Two coaches | Two coaches. |
| Six-car train | Four motor cars | Three motor cars. |
| | Two coaches. | Three coaches. |
| Seven-car train | Four motor cars | Four motor cars. |
| | Three coaches. | Three coaches. |
| Eight-car train | Five motor cars | Four motor cars. |
| | Three trailers | Four coaches. |

### CONTROL OF MULTIPLE-UNIT TRAINS AND LOCOMOTIVES.

Train control for electric cars was systematized in 1898. Mr. Frank J. Sprague should be given the credit for this work, which was of greatest importance in the history of electric traction.

In the early days, motor cars hauled trailers. Then followed a period when two mechanically coupled motor cars were required, each operated by a separate motorman. Electric wires running from car to car were then tried, but that plan was expensive and the space in a car for a controller which could handle the power for several cars was not available. Predictions were made that the electric locomotive would be used for local trains. When plans were made for the first electric trains in Chicago, in 1896, the General Electric engineers and the Westinghouse engineers reported that the multiple-unit motor-car train scheme was impossible, not practical if it were possible, and therefore valueless.

With the assistance of Mr. F. H. Shepard, who developed the details, Mr. Sprague perfected his multiple-unit plan, demonstrated the success of the scheme, and got it adopted by the South Side Elevated Railroad of Chicago. The first British road to use multiple-unit control was the Great Northern and City Railway, in 1904. Elec. World, March 5, 1904. Most of the electric trains in America and Europe are now operated by multiple-unit control equipment on motor cars and locomotives. More recently, the apparatus used has been adopted for large cars, many of which do not run in trains.

**Multiple-unit** train operation is defined by Sprague:

"A semi-autómatic system of control which permits of the aggregation of two or more transportation units, each equipped with sufficient power only to fulfill the requirements of that unit, with means at two or more points on the unit for operating it thru a secondary control, and a train line for allowing two or more of such units, grouped together without regard to end relation, or sequence, to be simultaneously operated from any point in the train." A. I. E. E., May, 1899; S. R. J., May 4, 1901.

Multiple-unit control is complicated, yet the units in the mechanism are so perfected that, like those in a clock, they form a reliable aggregate. The control equipment is wonderfully reliable.

Hudson and Manhattan Railroad in April, 1910, ran 504,565 car-miles in the severest motor-car train service in America; yet there was one delay per 72,081 car-miles, and one detention chargeable to control equipment per 168,188 car-miles.

**Train control** is distinguished from single-car control, as in the latter the switch contacts in the drum controller are usually operated by hand. In train control the contact switches are placed under the car and are controlled either by solenoid action on main-circuit contactor switches as in the Sprague-General Electric method; or by electro-magnetic action

on valves, and compressed air pressure which closes main-circuit contactor switches, as in the Westinghouse electro-pneumatic method.

**General Electric control** embodies the Sprague control. A train cable which carries a small line current connects the control circuits thruout the train. The contactors, which are simply heavy switches, are operated by power from this cable. The line voltage must exceed one-half the normal voltage before the switches will operate. The magnetic operation of the contactor causes a quick make and break of the circuit. The control scheme is positive and automatic. The rate of acceleration is fixed and, with the limit devices, a safe, continuous, and efficient action is provided, to prevent damage to field and armature.

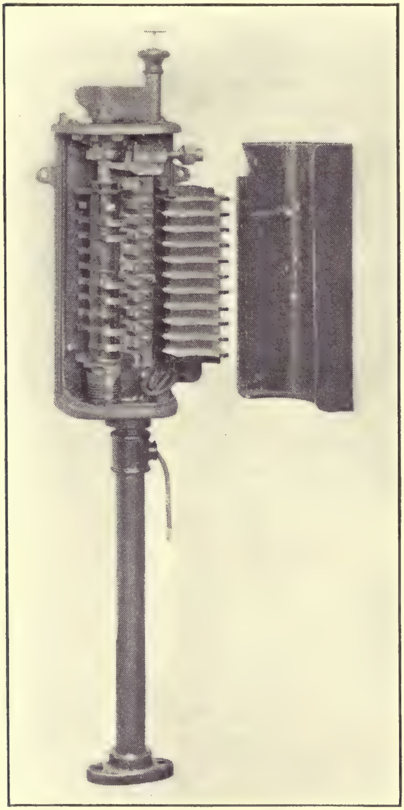

Fig. 66.—General Electric Train Controller.

The master controller is placed at each end of each car. The small current in the control circuit, about 2 amperes per motor car, passes thru the master controller to the several points along the train thru a 10-wire train line.

The master controller does not act directly, but governs the operation of motor controllers or contactors under each car, which in turn control the rheostats, switching, grouping of motors, paralleling, reversing, etc., in the (independent) power circuits on each car. Energizing the proper wires of any master controller on the train causes the corresponding switch contactors to move simultaneously on all the motor cars.

Auxiliary apparatus for each motor car includes switch contactor groups, cut outs, current relays to prevent overload, potential relay to open motor circuit in case of no voltage, circuit breakers, jumpers, etc.

**Westinghouse** Electric and Manufacturing Company developed the multiple-unit train control under the name of the electro-pneumatic system. The first road to adopt the Westinghouse plan was the Kings County Elevated Railway of Brooklyn in 1898. A description of the

early apparatus was given in St. Ry. Journ., October, 1899. This apparatus was perfected by F. H. Shepard and Wm. Cooper.

Westinghouse electro-pneumatic system involves the operation of

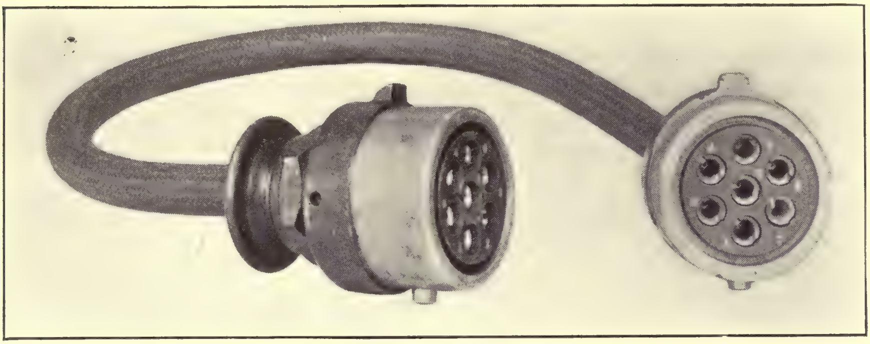

Fig. 67.

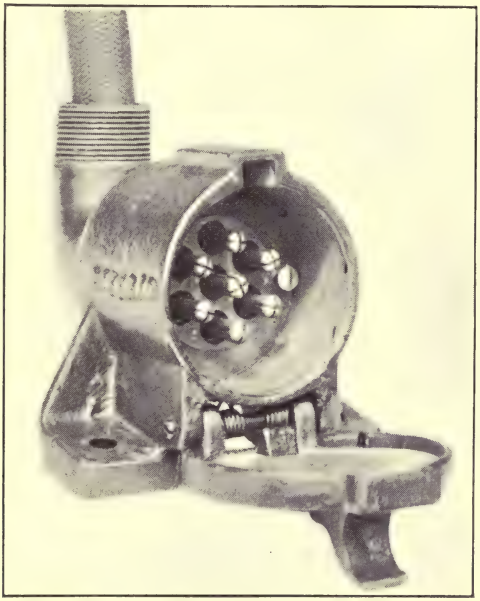

Fig. 68.

Figs. 67–68.—Electric Train Control Cable and Coupler Sockets.

circuit controlling switches by means of compressed air from the braking system. Small air cylinders, which close the motor circuit switches, operate against powerful springs, and when the air pressure is removed the springs quickly open the switch. Admission and release of air are

governed by electrically operated valves, the current for which comes from a 14-volt storage battery on each car. Line voltage is not brought into the car, cab, or controller. The train line carries only the 14-volt battery current. The motor circuit in each car is independent, and all wiring is well grouped at the motor truck end of the car. Master controllers are placed at each end of each car. All of the current which is used for the operation of all of the switches on the train goes thru the master controller which is being used, but the current for operating the switches on each motor car is obtained from the battery. Auxiliary

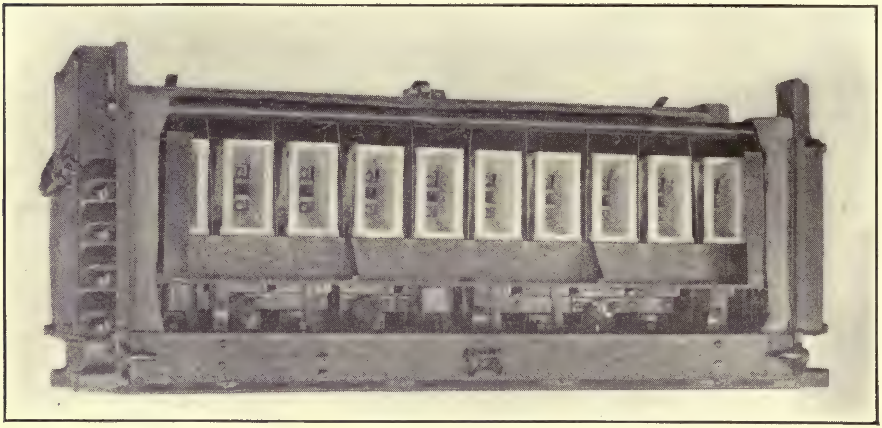

FIG. 69.—GENERAL ELECTRIC CONTRACTOR BOX.

apparatus includes a current limit switch for each motor, switch contactor groups, cut outs, circuit breakers, and car jumper connections.

Multiple-unit control equipments for light trains have recently been improved, and are superseding platform control. They are reliable, and remove all power wiring and heavy current-carrying parts from the vestibules, thus increasing the safety to employees and passengers.

Advantages of independent storage batteries versus line voltage, for automatic control systems:

Ability to reverse and buck motors, with quadruple equipment, when air brakes fail, and when power is off the line or when trolley leaves the contact wire.

Controller is independent of low line voltage

Fuses in control circuits, which may blow and render control inoperative in emergencies, are eliminated.

Trouble with defective insulation in train line, and false operation, are reduced.

Burning and scoring of contact fingers is reduced.

Danger from high line voltages in the cab is reduced.

Disadvantages of electric-pneumatic control:

Complication is caused by the additional equipment used.

Batteries, charging relays, and terminals must be mounted on rubber cushions, to prevent vibration from breaking the more delicate parts.

Air valves and pneumatic switches become clogged by scale in the air pipes, and a little dirt under the controlling fingers can prevent action in the low-voltage circuit.

**Control of locomotives** involves the same principles as control of motor-car trains; but the capacity of each motor is greater.

Acceleration must be relatively more uniform to prevent breakage of couplers, and strains on equipment. With uniformity of application, a very much greater effort can be exerted than when the pull is irregular. The controller must therefore have about double the number of points or steps used for passenger trains. The design is such that the current is not taken off the motors after it is once applied, *i. e.*, the circuit is not opened to change motor combinations from series to parallel, or to concatenation, or to change the number of poles. The so-called "bridging" plan of connection is desirable, not the open-circuit plan. Transformer-tap control is perfect, when there is a reasonable number of steps. Induction regulator control is ideal. Water rheostats, used on European locomotives, provide absolutely uniform graduations of resistance.

Results are a failure in railroading if the accelerating force is not properly applied to the train. In passenger service, an acceleration rate which varies from 1.2 to 1.6 m. p. h. p. s. is disagreeable, while a steady acceleration rate of 2.0 m. p. h. p. s. is not disagreeable. These matters need consideration, because the gain by uniform and rapid acceleration is so important. In locomotives for freight service, variation in control rate is sure to result disastrously, to jerk out drawbars, and to cause accidents and delays.

Control systems must be semi-automatic in action, and must also provide a check on the rate of acceleration, yet allow any lower rate which is desired. Should locomotives or cars break apart, the control current must be automatically and instantaneously cut out from the other locomotive or motor cars. The ability of the engineman to control the locomotive or train must not be lost, if the train cable is short-circuited.

**Multiple-unit operation with polyphase motors** under the ordinary conditions of railroad operation, was at first difficult because of the small air gaps and the difference of duty with varying driver diameters. Consult: St. Ry. Journ., March 24, 1906, page 462.

"Multiple-unit grouping and operation of three-phase motors is ordinarily impracticable because of the small slip." Sprague, to A. I. E. E., May 21, 1907, p. 706.

Later experience modifies the above statements. It is necessary to have motor-car wheels or locomotive drivers of about the same diameter. The wheels which have the slightly larger diameters, on any car or locomotive, whether coupled or not, will tend to run faster; and thus, by slip

and wear, the diameters tend to equalize. In the shop, some attention must be given to see that wheels do not have widely varying diameters.

Ganz Electric Co., on installations for Italian State Railway, and General Electric Company, for the Great Northern Railway locomotives, simply insert a small, but wasteful, resistance in the rotors of the motor. This is done automatically, on the Giovi locomotives.

Italian State Railway and Swiss Federal Railway have made tests with coupled three-phase locomotives, also with a locomotive placed at each end of the train, and on old and new locomotives having widely different driver diameters but with the same rated speed; and the record published shows that no serious difficulties have been encountered due to overheating of particular locomotives or motors.

Simplon locomotives, manufactured by Brown, Boveri and Company, use a squirrel-cage rotor, with a 7 per cent. drop in speed from no load to full load, which allows considerable variation in driver diameters.

## TECHNICAL DESCRIPTIONS OF MOTOR-CAR TRAINS.

**New York Central** motor-car trains provide for suburban service from the New York terminal (Grand Central Station) to North White Plains, 23.5 miles north on the Harlem Division; also to Hastings, 19 miles north on the Hudson Division. About 137 motor cars are used, each weighing 53 tons, and 63 coaches, each weighing 41 tons. Eight-car trains, 5 motor and 3 coaches, have 2400-h. p. in motor equipment. Such a train weighs over 420 tons and in accelerating at the rate of 1.3 m. p. h. p. s. requires a drawbar or tractive effort of about 138 pounds per ton or 55,200 pounds total. Almost twice this amount is available for traction, or, the accelerating rate could be doubled without slipping the wheels. One truck of each motor car is equipped with two 240-h. p., 660-volt, direct-current, interpole motors, with a 1.88 gear ratio. See Figure 53.

**Pennsylvania Railroad** in 1910, for its New York tunnel and terminal service, began the use of 157-ton 2500-h.p. electric locomotives; also 450-ton, 6-car, 2520-h.p. motor-car trains for its New York-Long Island, suburban service; and in 1911 to Newark, New Jersey. The motor-car train requires greater energy than the locomotive because of the continuity of service, the higher acceleration, and the frequent stops.

Motor-car train equipment already purchased consists of about 225 steel motor cars, for passenger service. Pennsylvania standard trucks are used with side-extended bolster springs and 8.5-foot wheel bases. Power equipment per motor car consists of two Westinghouse 215-h.p., direct-current motors. Forced draft is used to cool and to keep out the dust and grit. The entire axle is enclosed to keep the dust out of bearings. The motor equipment was described under Ventilation of Motors. See Figure 42, page 184. Each car is a motor car and weighs 53 tons.

**Long Island Railroad,** a subsidiary company, operates 138 steel 38- to 41-ton passenger motor cars, with two 200-h.p. motors per car, for suburban service west of Brooklyn to distant points on Long Island.

FIG. 70.—LONG ISLAND RAILROAD MOTOR-CAR TRAIN. STEEL COACHES.

**New York, New Haven & Hartford Railroad** purchased, in 1909, 4 motor cars and 6 trail coaches for its local service between New York City and Stamford, Connecticut, 34 miles. The motor cars are designed to pull 2 trail cars. Steel cars, built by the Standard Steel Car Company,

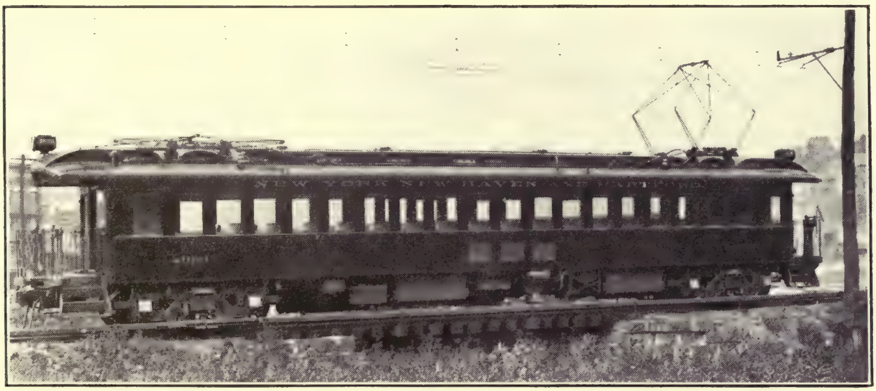

FIG. 71.—NEW YORK, NEW HAVEN AND HARTFORD MULTIPLE UNIT 87-TON MOTOR CAR. Operated in trains on the New York Division, 1909.

are 70 feet long. Seats are arranged for 76 passengers. Motor car weighs 87 tons and coaches 50. These are the heaviest motor cars yet built.

The electric system employed is the 11,000-volt, 25-cycle, single-phase.

Motors per car consist of four 150-h.p., 600-ampere, 235-volt Westinghouse units, with a 3.30 gear ratio. The gear is mounted on a quill which surrounds the axle (with 9/16-inch clearance). There are 4 drive pins which fit into pockets in the drivers, and helical springs which sur-

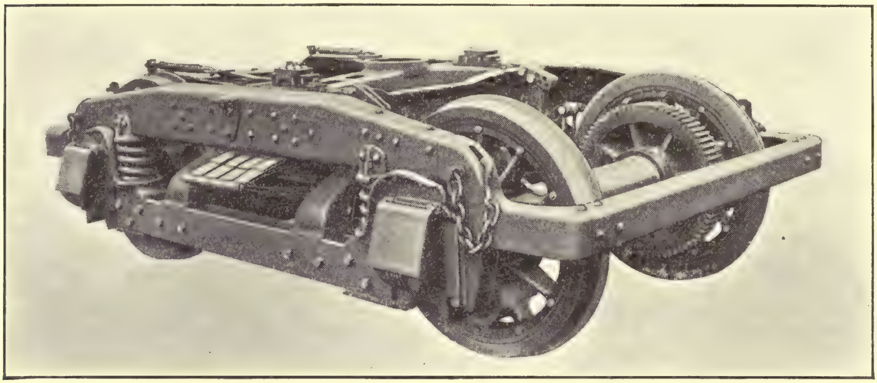

FIG. 72.—NEW YORK, NEW HAVEN AND HARTFORD TRUCK USED ON MOTOR-CAR TRAINS. Truck for two single-phase, 150-h. p., quill-mounted, Westinghouse motors; used on New York Division. Trucks built by Standard Motor Truck Company.

round the driving pins and carry the weight of the quill, gear, and half of the motor, and transmit the driving action or torque smoothly to the car wheels. This plan increases the weight and cost, and the diameter of the

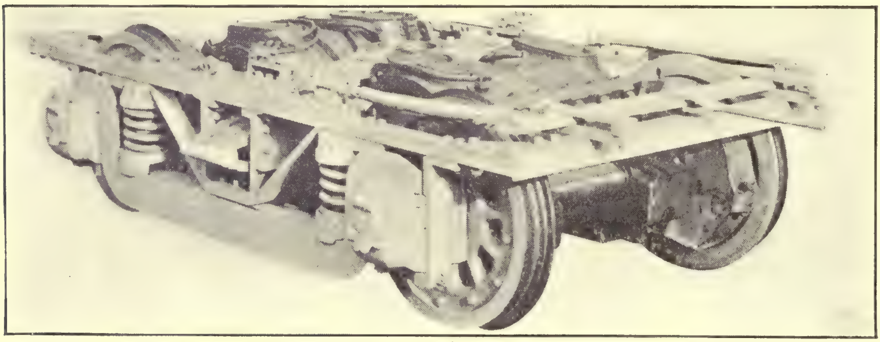

FIG. 73.—NEW YORK, NEW HAVEN AND HARTFORD TRUCK USED ON MOTOR-CAR TRAINS. Truck for two single-phase, 125-h. p., nose-mounted, General Electric motors used on New Canaan Branch.

gear seat and motor axle bearings. The motor is entirely spring-supported to effect good riding qualities and to minimize track destruction.

Control scheme used is the electro-pneumatic. Automatic acceleration is provided at the rate of .5 m. p. h. p. s. when hauling 2 coaches.

PERFORMANCE CHARACTERISTICS OF MOTOR CARS ON NEW YORK, NEW HAVEN & HARTFORD R. R., NEW YORK DIVISION.

| Current amperes. | Power factor. | Speed m. p. h. | Tractive effort lb. | Power h. p. | Notes or conditions. |
|---|---|---|---|---|---|
| 4000 | .830 | 17.5 | 17,600 | 820 | Gear ratio 3.3; wheels 42 in. |
| 2400 | .925 | 25.3 | 8,800 | 600 | One-hour rating at 235 volts. |
| 1800 | .952 | 30.4 | 5,600 | 448 | Continuous capacity with |
| 1200 | .970 | 41.0 | 2,700 | 290 | forced ventilation. |
| 1130 | .975 | 45.0 | 2,000 | 240 | Four motors per motor car. |

*Aspinwall*, Tests, Elec. Journal, Nov., 1909; Trucks, E. R. J., Dec. 12, 1908.

Motor-car trains with 3 cars weigh 187 tons and have 600-h.p. motor capacity; while the locomotive-hauled trains with 6 cars and double the seating capacity weigh about 402 tons and have 960-h.p. motor capacity. Significant comparisons may be made for suburban service.

**Chicago, Lake Shore & South Bend Railway** uses 4 single-phase, 125-h.p. motors per car and 3-car passenger trains. Cars weigh 56 tons. Trolley voltage is 6000 normally, but 600 volts alternating in the cities. Motors operate in series-parallel, 2 motors on each truck being in series.

A 250-kw. oil-insulated, self-cooled auto-transformer varies the voltage to the motors by means of a series of 8 taps. The master controller is operated with current from two 15-volt batteries. Manipulation of the controller handle operates magnets, which operate controller air valves, which in turn operate contactors in a main switch group to vary the voltage from the transformer from 62 volts to 250 volts.

Coaches without motors are equipped with master controllers. Snow plows not fitted with motors are designed to be pushed by motor cars and are equipped with master controllers and brake-train valves so that any number of cars can be coupled back of a plow and controlled from the look-out deck.

An 11-car train, made up of six 500-h.p. motor cars and 5 coaches, and operated by multiple-unit control, recently made an 80-mile run on this road. Incidentally, with the extremely small loss on the 6000-volt contact line, long trains can be operated successfully over long distances.

**Valtellina Railway** of Italy uses 58-ton motor cars which haul five 22-ton coaches, making a 168-ton train. There are 2 twin 250-h.p., 15-cycle, three-phase gearless motors, mounted on a hollow shaft, per motor car. Power is transmitted to 46-inch drivers by flexible couplings. See drawings in Parshall and Hobart's "Electric Railway Engineering."

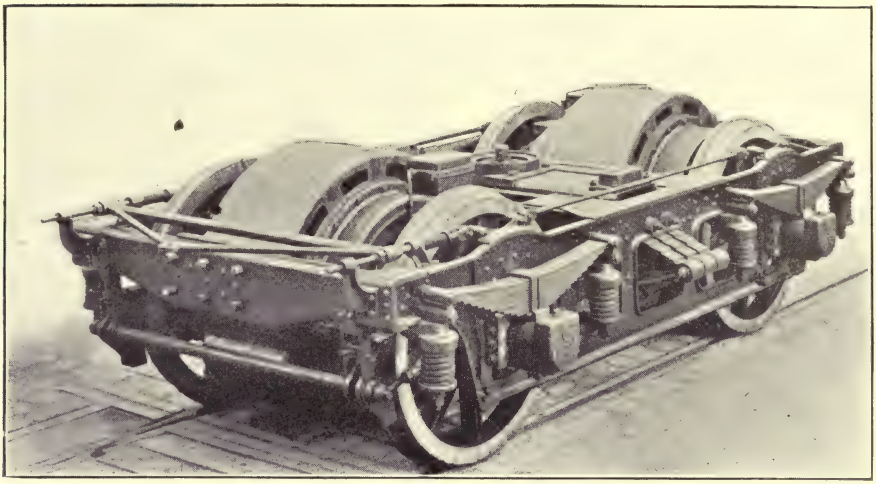

FIG. 74.—VALTELLINA RAILWAY, ITALY, MOTOR TRUCK FOR PASSENGER CARS, 1902.

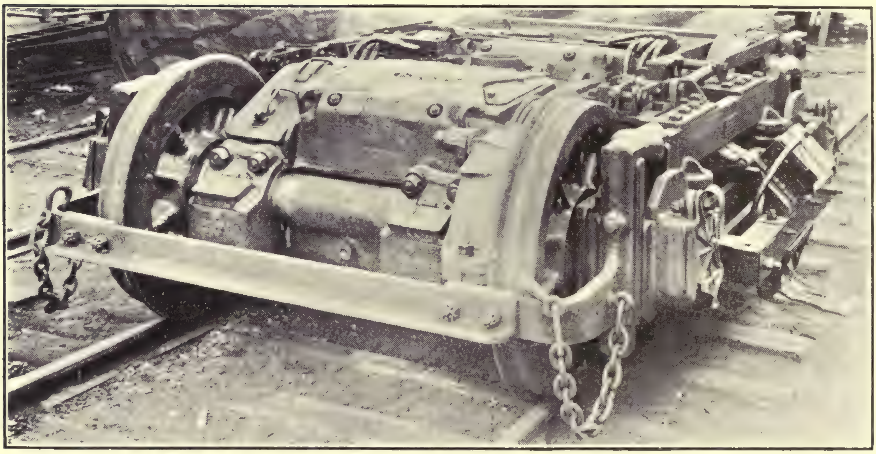

FIG. 75.—WEST JERSEY & SEASHORE RAILROAD, MOTORS MOUNTED ON BRILL TRUCKS.
G. E., No. 69, 240 h. p., 600-volt, direct-current motors.

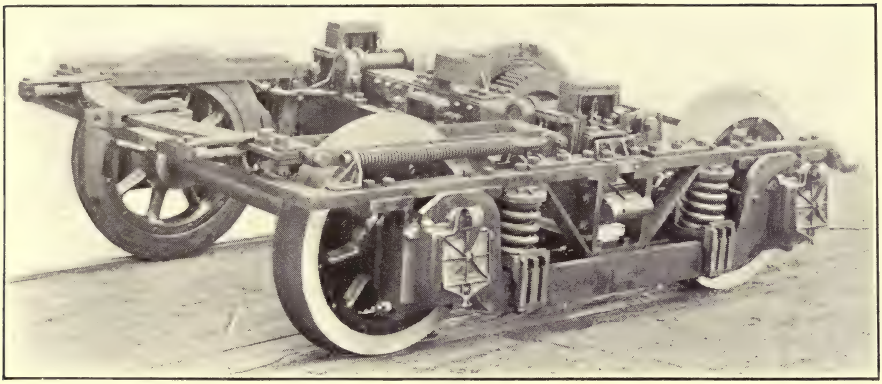

Fig. 76.—Motor-car Truck used on the Hudson & Manhattan Railroad.
Wheel base 78 inches. Wheels 34 inches. Weight of truck, 11,750 pounds; with two 160-h. p. motors, 22,750 pounds.

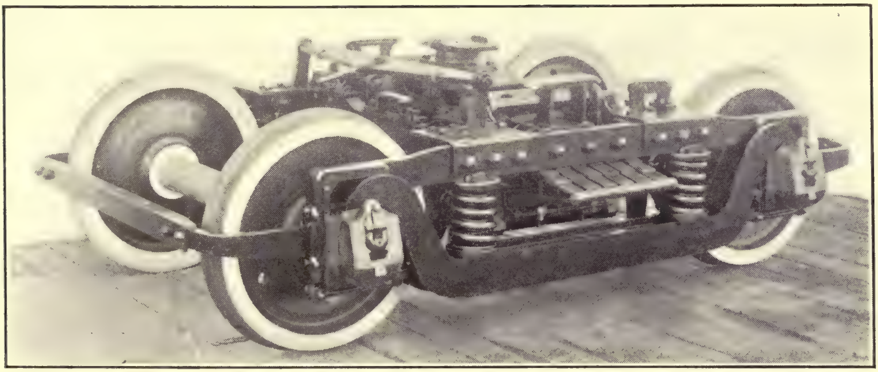

Fig. 77.—J. G. Brill Company's Motor-car Truck for Heavy Cars in High-speed Passenger Service.

## RAILWAYS OPERATING MOTOR-CAR TRAINS. PART I.

Geographical Distribution. Direct-current 600-volt System.

| Name of railway. | Largest city terminals. | Number of cars. | | | Number of miles. | | |
|---|---|---|---|---|---|---|---|
| | | Motor | Coach. | Total. | Between terminals. | Right-of-way. | Mileage. |
| Boston & Maine....... | Concord-Manchester.. | 12 | 0 | 12 | 16 | 16 | 50 |
| Boston Elevated...... | Boston suburbs..... | 225 | 91 | 316 | 11 | 6 | 26 |
| Boston & Worcester... | Boston-Worcester ... | 60 | 0 | 60 | 46 | 37 | 82 |
| New York Central.... | N.Y.-N.White Plains<br>N. Y.-Hastings. | 137 | 63 | 200 | 24<br>19 | 45 | 152 |
| Manhattan Elevated .. | Manhattan-Bronx ... | 895 | 759 | 1754 | 13 | 50 | 119 |
| Interborough Subway. | Manhattan-Brooklyn. | 910 | 336 | 1246 | 18 | 26 | 85 |
| Hudson & Manhattan. | New York-Jersey C.. | 200 | 0 | 200 | 8 | 8 | 18 |
| Brooklyn Rapid Trans. | Brooklyn........... | 659 | 269 | 928 | 13 | 50 | 107 |
| Pennsylvania R.R.: | | | | | | | |
| Long Island R.R.... | Brooklyn-Long I..... | 136 | 89 | 225 | 26 | 62 | 164 |
| Pennsylvania Tunnel & Terminal. | New York-Long I.... | 225 | 0 | 225 | 15 | 15 | 50 |
| | Jersey City-Newark.. | 50 | 0 | 50 | 9 | 9 | 20 |
| West Jersey & Sea. | Camden-Atlantic C... | 108 | 0 | 108 | 65 | 75 | 154 |
| Philadelphia Rapid Tr. | Philadelphia Elev..... | 150 | 0 | 150 | 8 | 8 | 18 |
| Philadelphia & West'n. | Phila.-Norristown.... | 28 | 0 | 28 | 17 | 20 | 40 |
| Albany Southern R.R.. | Albany-Hudson ..... | 45 | ........ | 45 | 38 | 34 | 62 |
| West Shore R.R....... | Utica-Syracuse...... | 21 | 0 | 21 | 44 | 43 | 114 |
| Rochester,Syracuse&E. | Syracuse-Rochester .. | 82 | 0 | 82 | 86 | 80 | 265 |
| Buffalo, Lockport & R. | Rochester-Lockport . | 19 | ........ | ...... | 57 | 50 | 58 |
| International Ry...... | Lockport-Buffalo .... | ...... | ........ | 26 | 25 | 20 | 74 |
| Lackawanna & Wyoming Valley. | Wilkes-Barre-Carbondale. | 35 | 1 | 361 | 25 | 25 | 50 |
| Wilkes-Barre & Hazelton. | Wilkes-Barre-Hazelton. | 6 | 1 | 70 | 31 | 31 | 32 |
| Mahoning & Shenango. | New Castle-Warren.. | ...... | ........ | ...... | 34 | ....... | 149 |
| Washington, Baltimore & Annapolis. | Baltimore-Washington. | 43 | 0 | 43 | 35 | 50 | 100 |
| Michigan United Rys .. | Jackson-Kalamazoo . | 30 | ........ | 159 | 71 | 125 | 254 |
| Grand Rapids, Grand Haven & Muskegon. | Grand Rapids-Muskegon. | 30 | 10 | 40 | 45 | 45 | 49 |
| Dayton & Troy....... | Dayton-Troy........ | 25 | 0 | 25 | 31 | 31 | 49 |
| Lake Shore Electric.. | Cleveland-Toledo.... | ...... | ........ | ...... | 119 | ....... | 215 |
| Scioto Valley Traction. | Columbus-Chillicothe. | 17 | 0 | 17 | 50 | ....... | 79 |
| Ohio Electric.......... | Dayton-Cincinnati... | ...... | ........ | ...... | 55 | ....... | 850 |
| Indianapolis,Col.& S.<br>Indianapolis&Louisv | Indianapolis-Louisville. | 10 | ........ | ...... | 117 | 83 | 68<br>55 |
| Illinois Traction ...... | St. Louis-Danville ... | 600 | 0 | 600 | 223 | ....... | 550 |

## RAILWAYS OPERATING MOTOR-CAR TRAINS, 1911. PART I.

### Direct-current 600-volt System.

| Name of railway. | Largest city terminals. | Number of cars. | | | Number of miles. | | |
|---|---|---|---|---|---|---|---|
| | | Motor | Coach. | Total. | Between terminals. | Right-of-way. | Mileage. |
| Aurora, Elgin & Chicago. | Chicago-Aurora<br>Chicago-Elgin<br>Chicago-Freeport | 115 | 0 | 115 | 40<br>42<br>125 | | 160 |
| South Side Elevated | Chicago | 200 | 200 | 400 | | | 47 |
| Chicago & Oak Park | Chicago | 65 | | 65 | | | 20 |
| Metropolitan West Side | Chicago | 225 | 280 | 505 | 10 | 27 | 57 |
| Northwestern Elevated | Chicago | 288 | 100 | 388 | | | 51 |
| Chicago & Milwaukee | Chicago-Milwaukee | 50 | 25 | 75 | 76 | 73 | 186 |
| Milwaukee Electric | Milwaukee-Watertown. | 30 | 15 | 45 | 51 | 40 | 137 |
| Milwaukee Northern | Milwaukee-Sheboygan | 12 | 9 | 21 | 57 | 54 | 64 |
| Fort Dodge, Des Moines & Southern. | Ft. Dodge-Des. M | 20 | | | 86 | 80 | 140 |
| Waterloo, Cedar Falls & Northern. | Waterloo-Waverly | | | | | 55 | 100 |
| Interurban Ry | Des Moines-Colfax | | | 55 | 24 | | |
| | Des Moines-Perry | | | | 35 | | 72 |
| Northern Texas | Ft. Worth-Sherman | | | 113 | 76 | 76 | 86 |
| Denver & Interurban | Denver-Boulder | 16 | 9 | 25 | 29 | 24 | 54 |
| Salt Lake & Ogden | Salt Lake-Ogden | 15 | 15 | 30 | | | |
| Spokane & Inland | Spokane-Hayden Lake<br>Spokane-Colfax<br>Spokane-Moscow | 25 | 50 | 75 | 46<br>77<br>91 | 80 | 287 |
| Puget Sound Electric | Seattle-Tacoma | 100 | 50 | 150 | 36 | 65 | 200 |
| Oregon Electric | Portland-Salem | 24 | | 24 | 50 | | 80 |
| Portland Railway | Portland-Cazadero | 30 | 33 | 63 | 40 | 45 | 472 |
| Northern Electric | Sacramento-Chico | 42 | 0 | 42 | 91 | | 130 |
| Southern Pacific | Alameda-Oakland | 100 | 60 | 160 | 15 | 15 | 100 |
| San Francisco, Oakland & San Jose. | Oakland suburbs | 38 | 40 | 78 | 6 | 6 | 35 |
| Los Angeles Pacific | Los Angeles-Santa Monica. | 121 | 225 | 486 | | | 214 |
| Pacific Electric | Los Angeles-Coast | | | 675 | 40 | | 600 |

## RAILWAYS OPERATING MOTOR-CAR TRAINS. PART I.

Direct-current 600-volt System.

| Name of railway. | Largest city terminals. | Number of cars. | | | Number of miles. | | |
|---|---|---|---|---|---|---|---|
| | | Motor. | Coach. | Total. | Between terminals. | Right-of-way. | mileage. |
| Central London | London | 68 | 172 | 240 | 7 | 7 | 13 |
| London Electric | | 383 | 525 | 908 | | | 168 |
| Metropolitan District | London | 197 | 235 | 432 | 25 | 25 | 49 |
| Baker St. & Waterloo | London | 36 | 72 | 108 | 3 | 5 | 10 |
| Charing Cross E. & H. | London | 60 | 90 | 150 | 8 | 8 | 16 |
| Great Northern, P. & B. | London | 72 | 146 | 218 | 10 | 10 | 20 |
| Great Northern & City | London | 35 | 35 | 70 | 4 | 4 | 8 |
| Great Western, M. & W.L. | London | 40 | 80 | 120 | 5 | 5 | 11 |
| Metropolitan Ry. | London | 130 | 210 | 340 | 30 | 30 | 60 |
| City & South London | London | 0 | 170 | 170 | 8 | 8 | 16 |
| Waterloo & City | London | 20 | 12 | 32 | 2 | 2 | 4 |
| London & North Western | London | | | | 15 | 15 | 30 |
| Mersey Ry. | Liverpool-Birkenhead | 24 | 37 | 61 | 5 | 5 | 10 |
| Lancashire & Yorkshire | Liverpool-Southport | 80 | 52 | 132 | 40 | 40 | 82 |
| Liverpool Overhead | Liverpool-Seaforth | 44 | 7 | 51 | 7 | 7 | 13 |
| North-Eastern. | New Castle-on-Tyne | 62 | 44 | 106 | 35 | 35 | 82 |
| Rhine Shore | Cologne-Bonn | 10 | 10 | 20 | 18 | 18 | 30 |
| Berlin Overhead & Under. | Berlin | 139 | 52 | 191 | 14 | 14 | 26 |
| Paris-Metropolitan | Paris | 570 | 381 | 951 | 31 | 31 | 63 |
| Paris-Lyons-Mediterranean. | Paris | | | | | | 40 |
| Paris-Orleans | Paris-Juvisy | | | | 12 | 12 | 46 |
| West of France | Paris-Versailles. | | | | | | 16 |
| Milan-Varese-Porto Ceresio | Milan-Porto Ceresio. | 20 | 20 | 40 | 46 | 46 | 81 |

Fig. 78.—Cologne-Bonn Railway. Motor-car Train.
Two 32-ton motor cars each with two 130-h. p., 500-volt, direct-current, interpole, Siemens motors; operating on a 1000-volt trolley line, and two 18-ton coaches per four-car train, 1906.

## RAILWAYS OPERATING MOTOR-CAR TRAINS. PART II.

Direct-current 600-volt System.

| Name of railway. | No. of motor cars. | Motors No. and h. p. | Tons, motor car. | Tons per coach. | Train made of: Motor | Coaches. | Total. |
|---|---|---|---|---|---|---|---|
| Boston & Maine | 12 | 4–40 | ...... | ...... | 1 | 1 | 2 |
| Boston Elevated | 225 | 2–175 | 33 | ...... | 6 | 0 | 6 |
| Boston & Worcester | 60 | 4–50 | 25 | ...... | 1 | 0 | 1 |
| New York Central | 137 | 2–240 | 54 | 41 | 5 | 3 | 8 |
| | | | | | 4 | 2 | 6 |
| Manhattan Elevated | 895 | 2–125 | 27 | 20 | 4 | 2 | 6 |
| | | | | | 4 | 3 | 7 |
| | | | | | 5 | 3 | 8 |
| Interborough Subway | 910 | 2–240 | 50 | 37 | 3 | 2 | 5 |
| | | | | | 5 | 3 | 8 |
| | | | | | 7 | 3 | 10 |
| Hudson & Manhattan | 200 | 2–160 | 35 | ...... | 6 | 0 | 6 |
| Brooklyn Rapid Transit | 659 | 2–200 | 36 | 17 | 4 | 2 | 6 |
| | | | | | 3 | 2 | 5 |
| | | | | | 2 | 1 | 3 |
| Pennsylvania R. R.: | | | | | | | |
| Long Island R. R. | 136 | 2–200 | 40 | 3 | 4 | 2 | 6 |
| Penn. Tunnel & Terminal | 225 | 2–215 | 53 | ...... | 6 | 0 | 6 |
| Newark Rapid Transit | 50 | 2–160 | .. | ...... | ...... | ...... | ...... |
| West Jersey & Seashore | 93 | 2–240 | 47 | ...... | 7 | 0 | 7 |
| West Jersey & Seashore | 15 | 2–240 | 52 | ...... | 7 | 0 | 7 |
| Philadelphia Elevated | 150 | 2–125 | ...... | ...... | 5 | 0 | 5 |
| Philadelphia & Western | 28 | 4–75 | ...... | ...... | 3 | ...... | 3 |
| Albany Southern | 45 | 4–80 | ...... | ...... | ...... | 0 | ...... |
| West Shore R. R. | 21 | 4–75 | 40 | ...... | 2 | 0 | 2 |
| Rochester, Syracuse & Eastern | 82 | 4–125 | 42 | ...... | 1 | 0 | 1 |
| Buffalo, Lockport & Rochester | 19 | 4–125 | ...... | ...... | 2 | 0 | 2 |
| Lackawanna & Wyoming Val. | 35 | 2–150 | 31 | ...... | 2 | 0 | 2 |
| Wilkes-Barre & Hazelton | 6 | 4–125 | 43 | ...... | ...... | ...... | ...... |
| Washington, Baltimore & Annapolis. | 40 | 4–100 | 39 | ...... | 1 | 0 | 1 |
| | 3 | 4–125 | 43 | ...... | 1 | 0 | 1 |
| Lake Shore Electric | 20 | 4–90 | 41 | ...... | 1 | 0 | 1 |
| Grand Rapids, Grand Haven & M | 30 | 2–150 | ...... | ...... | ...... | ...... | 3 |
| Scioto Valley Traction | 17 | 4–125 | ...... | ...... | 1 | 0 | 1 |
| South Side Elevated, Chicago | 200 | 2–52 | ...... | ...... | 4 | 1 | 5 |
| | | 2–90 | 25 | ...... | 3 | 2 | 5 |
| Chicago & Oak Park | 65 | 2–160 | ...... | ...... | 3 | 2 | 5 |
| Metropolitan West Side | 225 | 2–160 | 33 | 16 | 4 | 2 | 6 |
| Aurora, Elgin & Chicago | 115 | 4–125 | ...... | ...... | ...... | ...... | 3 |
| Northwestern Elevated, Chicago | 228 | 2–160 | ...... | ...... | 4 | 2 | 6 |
| Chicago & Milwaukee Electric | 50 | 4–75 | 38 | ...... | 3 | 0 | 3 |
| Milwaukee Electric | 30 | 4–125 | 40 | 18 | 1 | 2 | 3 |
| Indiana Union Traction | 285 | 4–85 | ...... | ...... | 1 | 0 | 1 |
| Indianapolis & Louisville | 10 | 4–75 | ...... | ...... | 2 | 0 | 2 |
| Illinois Traction | 600 | 2–100 | 47 | ...... | 1 | 1 | 2 |
| Ft. Dodge, Des Moines & South | 20 | 4–75 | ...... | ...... | ...... | ...... | 2 |
| Puget Sound Electric | 100 | 4–125 | 43 | ...... | 3 | 0 | 3 |
| North Shore Ry., California | 37 | 2–125 | ...... | ...... | ...... | ...... | ...... |
| Southern Pacific Company | 100 | 4–125 | 54 | 32 | 2 | 2 | 4 |
| San Fran. Oakland & San Jose | 38 | 2–125 | ...... | 30 | 6 | 4 | 10 |
| Los Angeles Pacific | 121 | 4–75 | 38 | ...... | ...... | ...... | ...... |

RAILWAYS OPERATING MOTOR–CAR TRAINS. PART II.
Direct-current, 600-volt System. 2000-pound Tons.

| Name of railway. | No. of motor cars | Motors No. and h. p. | Tons motor car. | Tons per coach. | Train made up of | | |
|---|---|---|---|---|---|---|---|
| | | | | | Motor cars. | Coaches. | Total. |
| Central London | 68 | 4–65 | 28 | 16 | 2 | 5 | 7 |
| London Electric Railway Co.: | | | | | | | |
| Metropolitan District | 197 | 4–150<br>2–240 | 32<br>32 | 20<br>20 | 3<br>4 | 4<br>6 | 7<br>10 |
| Baker Street & Waterloo | 36 | 2–240 | 31 | 20 | 2 | 4 | 6 |
| Charing Cross, E. & H. | 60 | 2–240 | 30 | ....... | 2 | 3 | 5 |
| Great Northern, Pic. & B. | 72 | 2–240 | 31 | 19 | 2 | 4 | 6 |
| Great Northern & City | 35 | 2–125 | 25 | 22 | 2 | 4 | 6 |
| Great Western, M. & W. L. | 40 | 4–150<br>2–125 | 39 | 25 | 2 | 4 | 6 |
| Metropolitan, London | 130 | 4–150<br>4–240 | 42<br>46 | 19 | 4 | 5 | 9 |
| Waterloo & City | 20 | 2–80 | ....... | ....... | 2 | 2 | 4 |
| Mersey Railway | 24 | 4–100 | 35 | 25 | 2 | 3 | 5 |
| Lancashire & Yorkshire Liverpool-Southport. | 80 | 4–150<br>2–125 | 51<br>25 | 40 | 2 | 2 | 4 |
| Liverpool Overhead | 44 | 2–100 | 16 | 14 | 2 | 1 | 3 |
| North-Eastern | 62 | 2–150 | 32 | 25 | 2<br>5 | 1<br>4 | 3<br>9 |
| Cologne-Bonn | 10 | 2–130 | 32 | 18 | 2 | 2 | 4 |
| Berlin Overhead & Underground | 139 | 4–75 | 18 | ....... | 5 | 3 | 8 |
| Berlin-Gross Lichterfelde | 24 | 2–125 | ....... | ....... | ....... | ....... | ....... |
| Paris-Metropolitan | 248 | 2–240 | 40 | 19 | 2 | 6 | 8 |
| Paris-Orleans | 100 | 4–125<br>2–175 | ....... | ....... | 3 | 2 | 5 |
| Milan-Varese-Porto Ceresio | 20 | 4–160 | 48 | 34 | 2 | 2 | 4 |

City and South London has fifty-two 464-h.p. locomotives; Metropolitan Railway, London, has eleven 800 h.p.; North-Eastern, six 640-h.p.; and Paris-Orleans eleven 1000-h.p. locomotives.

Fig. 79.—Rotterdam-Hague-Scheveningen. Motor-car Train.
Two 54-ton motor cars, each with two 175-h. p., single-phase motors and one 34-ton coach per three-car train.

RAILWAYS OPERATING MOTOR-CAR TRAINS, 1910. PART III.
Three-phase System. 2000-pound Tons.

| Name of railway. | No. of motor cars. | Motors No. and h. p. | Tons, motor car. | Tons per coach. | Train made of | | |
|---|---|---|---|---|---|---|---|
| | | | | | Motor cars. | Coaches. | Total. |
| Stansstad-Engelberg | ........ | 2-35 | ...... | ...... | ........ | ........ | ...... |
| Burgdorf-Thun | 6 | 4–64 | 36 | ....... | 1 | 1 | 2 |
| Zossen Tests of 1903 | 1 | 4–250 | 85 | ....... | 1 | 0 | 1 |
| | 1 | 4–250 | 100 | ....... | 1 | 0 | 1 |
| London-Port Stanley, Ontario, 1905. | ....... | 2–65 | ...... | ...... | ........ | ........ | ...... |
| Valtellina, 1902 | 10 | 2–150 | 53 | 30 | 2 | 1 | 3 |
| | | 4–150 | 32 | 20 | 1 | 2 | 3 |
| | | 2–250 | 58 | 21 | 1 | 5 | 6 |

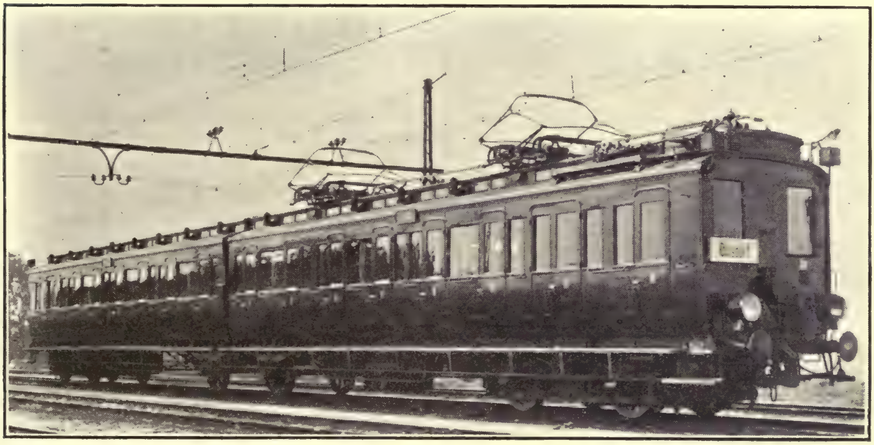

FIG. 80.—BLANKANESE-HAMBURG-OHLSDORF MOTOR-CAR TRAIN.
Two 69-ton motor cars each with two 200-h. p., single-phase motors.

FIG. 81.—BAVARIAN STATE RAILWAY. MURNAU-OBERAMMERGAU LINE MOTOR CAR TRAIN. Two 100-h. p., single-phase Siemens motors per motor car and coach.

FIG. 82.—VIENNA-BADEN RAILWAY. MOTOR-CAR TRAIN. Four 60-h. p., single-phase motors per motor car.

RAILWAYS OPERATING MOTOR-CAR TRAINS. PART IV.

Single-phase System.

| Name of railway. | No. of motor cars. | No. of coaches. | Motors No. & h.p. | Tons motor car. | Tons per coach. | Trains made of Motor. | Trains made of Coaches. | Trains made of Total. |
|---|---|---|---|---|---|---|---|---|
| New York, New Haven&H.: New York-Stamford.... | 4 | 6 | 4–150 | 87 | 50 | 3<br>2 | 4<br>3 | 7<br>5 |
| New Canaan-Stamford.. | 2 | 2 | 4–125 | 70 | 35 | 1 | 1 | 2 |
| Harlem River Branch .. | 4 | 12 | 4–150 | ..... | ....... | ........ | ........ | ...... |
| New York, Westchester & Boston. | 60 | ........ | 4–150 | ....... | ....... | ........ | ........ | ...... |
| Long Island: Sea Cliff Div. | 6 | 0 | 2–50 | ....... | ....... | 1 | 0 | 1 |
| Baltimore & Annapolis Short Line. | 12 | 0 | 4–100 | 50 | ....... | 3 | 0 | 3 |
| Erie R.R.: Rochester Div. | 6 | 6 | 4–100 | 48 | 28 | 2 | 2 | 4 |
| Windsor, Essex & Lake S. | 8 | 0 | 2–100 | ....... | ....... | ........ | ........ | ...... |
| Ft. Wayne & Springfield.. | 4 | 0 | 4–75 | 40 | ....... | 1 | 0 | 1 |
| Indianapolis & Cincinnati. | 25 | 0 | 4–100 | 50 | ....... | 1 | 0 | 1 |
| Chicago, Lake Shore & South Bend. | 24<br>7 | 0<br>0 | 4–125<br>4–75 | 56<br>....... | .......<br>....... | 3<br>1 | 0<br>0 | 3<br>1 |
| Rock Island Southern..... | 6<br>4 | 0<br>0 | 4–100<br>4–125 | 52<br>52 | .......<br>....... | 1<br>1 | 0<br>0 | 1<br>1 |
| Colorado & Southern: Denver & Interurban... | 16 | 10 | 4–125 | 58 | 37 | 1 | 1 | 2 |
| Spokane & Inland Empire. | 25 | 10 | 4–100 | 42 | 31 | 2 | 1 | 3 |
| Visalia Electric.......... | 6 | 6 | 4–75 | 40 | 28 | 1 | 1 | 2 |
| San Francisco, Vallejo and Napa Valley. | 2<br>9 | 10<br>........ | 4–75<br>4–100 | 40<br>....... | .......<br>....... | 1<br>........ | 1<br>........ | 2<br>...... |
| Midland Ry., England .... | 1<br>2 | 6<br>........ | 2–150<br>2–180 | 41<br>45 | 21<br>21 | 1<br>1 | 2<br>2 | 3<br>3 |
| London, Brighton & South Coast. | 16<br>30 | 8<br>60 | 4–115<br>4–175 | 55<br>60 | 35<br>35 | 4<br>2 | 2<br>4 | 6<br>6 |
| French Southern.......... | 30 | ........ | 4–125 | 61 | ....... | ........ | ........ | ...... |
| Rotterdam-Hague-Scheveningen. | 25 | 9 | 2–175 | 54 | 34 | 2 | 1 | 3 |
| Blankanese-Hamburg-Ohlsdorf. | 110 | 0 | 2–200 | 69 | ....... | 2 | 0 | 2 |
| Bernese Alps............ | 3 | ........ | 4–220 | 59 | ....... | ........ | ........ | ...... |
| Vienna-Baden Interurban. | 19 | 0 | 4–60 | 40 | 19 | 2 | 1 | 3 |
| Parma Provincial........ | 10 | 30 | 2–70 | ....... | ....... | 1 | 3 | 4 |

Mileage of all single-phase roads is given in "Electric Systems," Chapter IV.

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## CHAPTER VII.

# CHARACTERISTICS OF ELECTRIC LOCOMOTIVES.

### Outline.

**Introduction:**

Electric locomotives not a primary power.

Comparison of steam and electric locomotives.

**Physical Characteristics:**

Capacity.—Drawbar pull, its quality and amount; drawbar pull at high speeds; acceleration rates utilized, speed and unification of speed, mileage of locomo tives and cars, power developed per ton.

Other Physical Features.—Mechanical efficiency, simplicity, safety in operation, reliability in service.

**Commercial Considerations:**

Traffic and earnings, car movement, terminal capacity, loads, freight haulage Maintenance and repairs, wages and time saved.

Economy of Power.—Utilization, effective and efficient, regeneration of power, water powers, economy of fuel, cost of service, earnings from investments.

**Advantages over Motor-car Trains:**

Independent units, use as freight cars, danger to passengers, high voltages in motor, design of motors, cost of equipment, cost of maintenance.

**Electric Locomotive Design:**

General review, mistakes in design, center of gravity, mechanical data, weight factor, weight analysis.

**Mechanical Transmission of Motive Power:**

Methods outlined, driver diameters, gearless motors, geared motors, cranks and side rods, cranks with jackshafts and side rods

**Cost of Electric Locomotives.**

**Literature.**

## CHAPTER VII.

# CHARACTERISTICS OF ELECTRIC LOCOMOTIVES.

### INTRODUCTION.

The application of electric locomotives as a motive power for railroad train haulage is now considered.

**Locomotives are only a part of a motive power equipment.**—Steam locomotives require a repair shop; round house for frequent washing of flues; stations distributed along the route, with men and machinery to store and handle the coal, and to pump the water to tanks; locomotives to haul and distribute coal to these stations; and a loaded coal and water tender in each train. Electric locomotives require a repair shop and an inspection house. The coal is not hauled with the train, but it is carried to one central point, if water power is not used. Electric locomotives also require a central power plant with a complete equipment of boilers, steam turbines, alternating-current generators, reliable transmission and contact lines, and sometimes rotary converter substations.

Comparison of steam and electric locomotives with reference to their physical characteristics, and the financial results therefrom, is advantageous because on an important railroad division the ultimate limit of the economical load is generally prescribed by the power and other qualities of the locomotive. Such a comparison indicates the nature and also the extent of the improvements which are possible thru the substitution of electric for steam traction.

Steam locomotives are prime movers, that is, energy-generating machines as contrasted with electric locomotives which are simply energy-collecting machines. This fundamental difference affects operating characteristics and features of design.

Electric locomotives do not yet operate in the best fields, on long divisions in dense freight traffic and on long mountain grades. The development in design is not the result of long years of experience, and electric locomotives are generally not handled by such well-trained motive-power men as found in steam railroad organizations. The demonstration of results must be made by argument, in part, because in some cases an opportunity has not yet been given to show the full measure of the financial advantages.

See Electric Locomotive History, to 1895, under History. See Speed-torque Characteristics of Electric Locomotives under Motors. See Techical Description of Electric Locomotives in the next three chapters.

**PHYSICAL CHARACTERISTICS.**

Physical advantages of electric locomotives arise from the inherent characteristics of electric motive power.

**Capacity** is the most important of these advantages because as already explained capacity bears directly upon economy of train operation. The capacity of steam locomotives is too limited.

"The gage is too narrow for admitting a properly designed boiler upon a large locomotive. Many steam locomotives have reached the limit of their capacity because the limited gage prevents the boiler being made larger." Angus Sinclair.

There is a reasonable objection to the heavy and complicated Mallet compound, if a simple and efficient design of electric locomotives, unlimited by track gage, is available.

"The men in charge of the railways of this country have struggled for 15 years with the greatest problem of our times—how to move a load whose weight increases 10 per cent. a year with a steam locomotive whose power increases but 2 1/2 per cent. a year. The limit of safe, speedy, and reasonable service with existing facilities has been reached." James J. Hill to Kansas City Commercial Club, Nov. 16, 1907.

"Expenses are per train-mile and receipts are per ton-mile," a statement of economists, is a valuable one to apply, if sufficient power is provided to move the heaviest tonnage per train on the level and up the grades at a reasonable speed. The statement is valueless without good speed, since the economical use of the equipment, the track, and the terminals are vital factors in the cost of transportation; further the cost of trainmen's wages, which varies with the train speed, equals the cost of fuel for steam locomotives.

"The traffic which American railroads have to handle is continually increasing. But it is difficult for us to increase our facilities in the same ratio. We are up against the matter of motive power, and in that we have reached the limit of development under steam, so long as the present gage is employed. Widening of the gage would increase the capacity of our engines. But it is hardly possible to think of rebuilding the railroads. Electricity is the next best thing, and I believe we will come to that to increase our power and our train load." E. H. Harriman, October, 1907.

Three months prior to the death of Mr. Harriman, which occurred September 10, 1909, it was announced that all suburban trains near Oakland would use electric power to give immediate relief to the crowded traffic conditions; and further that the Sacramento Division of the Southern Pacific Company would ultimately be electrified to increase the train load and speed.

Increased locomotive capacity offers immediate relief from congested traffic conditions that seem almost hopeless under some existing circumstances. A modern steam locomotive is a splendid piece of apparatus, but where conditions of service have grown beyond what can be handled efficiently by steam locomotives, the powerful electric locomotive steps in and takes up the task, and solves some of the railroad problems.

"Whenever traffic is dense enough, electric traction not only materially decreases the operating cost per ton-mile, but either accomplishes this end with a material decrease in the motive power equipment, or can handle as much as 50 per cent. more traffic than can be handled under the most favorable conditions of steam operation." Graham, Third Vice-president, Erie Railroad, 1910.

Capacity is available with electric traction because the source of energy is a large central station, where, for important service and for heavy grades, ample power and great temporary overloads may be advantageously employed. The steam locomotive has its source of power upon its back. The electric locomotive has a power station behind it.

The backbone of railroad business, the freight traffic, now calls for heavier trains and faster schedules. Railway managers demand this because expenses are per train-mile and per train-hour. This demand cannot be met by the steam locomotive, for its capacity and weight per ton, per axle, and per foot of wheel base has reached uneconomical and undesirable limits.

Capacity is all-important in railroading, for the public and for the investor. Service is demanded, to transport freight and passengers safely, rapidly, and in very heavy trains.

Capacity in the electric locomotive results from:

Drawbar pull, its quality and amount.
Drawbar pull at high speed.
Acceleration rates.
Speeds utilized.
Mileage of locomotives.
Power developed per ton.

**Drawbar pull, its quality and amount,** governs the tonnage hauled in each train. The matter is therefore of fundamental importance. When the weight on the drivers, the motor design, or the steam pressure, piston area, leverage, and condition of the rails are fixed, the amount of the drawbar pull depends entirely on the character or quality of the effort.

Reciprocating efforts of a steam locomotive, during each revolution of the drivers, cause a variation in tractive effort of from 25 to 45 per cent. from the average effort. Circumferential efforts obtained from motor armatures are uniform, and there is no tendency of drivers to slip at particular points.

The maximum drawbar pull of the steam locomotive, with its varying reciprocating effort, is about 22 per cent. of the weight on drivers, while comparable values for the electric locomotive are from 26 to 34 per cent. Based on total weights, including the tender, the drawbar pull of electric locomotives is from 40 to 50 per cent. greater than steam locomotives.

Mallet-compound steam freight locomotives weighing 250 tons, with 158 tons on drivers, ordinarily develop a drawbar pull of about 60,000 pounds, while electric freight locomotives weighing 115 tons, all on drivers, ordinarily develop 60,000 pounds.

New York Central steam locomotives of the heaviest Altantic type, with the tender, weigh 150 tons, of which 47 tons are on two pairs of drivers; and those of the heaviest Pacific type weigh 175 tons, of which

67 tons are on the three pairs of drivers. Its electric locomotive, of 1909, weighs 115 tons, of which 71 tons are on four pairs of drivers. The steam locomotive weighs 15 to 10 pounds while the electric locomotive weighs about 7 pounds per pound of effective drawbar pull.

Grand Trunk Railway 66-ton locomotives develop 45,000 pounds drawbar pull or .34 of the weight, before slipping the drivers.

Slipping of drivers is easy to avoid with electric traction, yet tractive forces cannot be used which are greater than that indicated by the product of the coefficient of tractional friction and the weight on the drivers.

## TORQUE OF MOTORS.

Direct-current motors when connected in series have double their normal drawbar pull per kilowatt input. Compound steam locomotives, when connected for starting conditions as simple engines, develop double their normal drawbar pull, but with *double* the steam input which is used in compound. Two electric locomotives when coupled at the head of a train are operated on the multiple-unit plan, by one engineman; and the control of each locomotive is automatic and synchronous, and thus equal tractive effort from each unit is provided.

Three-phase motors furnish a drawbar pull which in its amount varies directly as the square of the impressed line voltage. Thus, with a 10 per cent. drop in voltage, due to line loss, the drawbar pull is reduced 19 per cent.; and with a 20 per cent. drop, is reduced 36 per cent. The trouble is cumulative since the drawbar pull in starting is a maximum, the power factor of the motor is very low, a heavy volt-ampere input is required for the work, and the heavy current produces excessive line drop. Transformer substations on 3500-volt, three-phase railroads must be placed 3 to 5 miles apart to prevent a large line loss. The drawbar pull is low because the magnetic field strength is lowered by design to reduce the steel losses and the magnetic leakage. The drawbar pull is increased by decreasing the air gap, or by inserting wasteful resistance in the rotor in starting.

**Single-phase series motors** produce a pulsating effort.

"The torque of the motor pulsates at twice the circuit frequency and the electrical torque varies from its maximum value to zero and may even assume a negative value if the field flux is not in time-phase with the armature current. This condition does not exist with reference to the mechanical torque which reaches the drivers, because of the inertia and of the elasticity of the medium between the electrical and mechanical torque. When the drivers are stationary the torque is transmitted thru springs at a certain definite value. In order that the mechanical torque may reach zero fifty times per second, it would be necessary for the field armature structures to be returned by the springs to the zero torque an equal number of times in this period. The inertia of the moving armature and the elasticity of the springs causes a vibra-

tion thru very narrow limits, and the torque which reaches the drivers and which fluctuates with the electrical torque will be almost constant at a value equal to about one-half of the maximum electrical torque. Observations show that the mechanical torque exerted varies only slightly, and that the slipping of the drivers is almost impossible." St. Ry. Journ., April 14, 1906, p. 591.

**Methods used for smoothing out the pulsating torque** or drawbar pull of single-phase motors are to employ flexible spring couplings between the armature shaft and the axle. In the 15-cycle, 125-ton locomotive built by the General Electric Company in 1909 (see Elec. Ry. Journ., May 8, 1909), a series of leaf springs, arranged radially around the armature shaft, provides a flexible coupling which is interposed between the armature shaft and the crank-shaft. In the New Haven gearless type, 25-cycle passenger locomotives and motor cars, each end of the quill-mounted armature shaft is provided with 6 pins which connect to the drivers thru helical springs. In the New Haven geared type freight locomotives, pinions are placed at the ends of the armature shaft and they mesh into gears which are mounted on a quill surrounding the axle, and each end of the quills is provided with 6 driving arms and helical springs to equalize the torque. Incidentally, but of greatest importance, the transmission of strains and shocks from the track to the motors is avoided. In the New Haven crank-type freight locomotive, heavy helical compression springs are interposed between the split spider of a large radius armature and the spider mounted on the motor shaft.

**Shouldering or nosing** seldom exists in electric locomotives. The drawbar pull is forward and effective, not an alternating right and left thrust. Therefore the loosening of spikes, the maintenance of the rail gage and alignment, and the care of the roadbed are decreased. Oscillations, caused by the coned surface of driver treads, may not be avoided, but are easily dampened by side springs, and are not destructive.

**Temperatures** in winter do not decrease the drawbar pull of electric locomotives and delay the service. Steam locomotives have less tractive effort in winter on account of a decrease in the mean-effective steam pressure, condensation on the cylinder walls and piston rods, radiation of heat from boilers, chilled furnaces, etc. Rating Tables were given under "Operating Characteristics of Steam Locomotives," page 64.

Electric locomotive drawbar pull and speed are increased by cold and windy weather, at the time when the increased friction requires greater power to haul the train. On many roads this increased capacity has been found to be of great value and "the aggregate delay has been less, a fact particularly noticeable in times of snow storms." Sprague.

**Drawbar pull is effective** in hauling the cars, because the mechanical friction of electric locomotives is less, particularly so in high-speed service; because the higher tractive effort requires less dead weight; and because the 30- to 60-ton coal and water tender are eliminated.

For example, in the New York Central electric zone, the common electric passenger locomotive weighs 100 to 115 tons; it hauls the same train which, outside of the electric zone, is hauled by a 171-ton steam locomotive. To show the saving in non-revenue-bearing ton-mileage, each steam locomotive averaged 25,620 ton-miles monthly of which 49

per cent. was useful car-ton-miles, while each electric locomotive averaged 33,210 ton-miles monthly, of which 65 per cent. was useful car-ton-miles. The total saving in weight is reported as 11 per cent. Note also:

STEAM AND ELECTRIC TRAIN WEIGHTS, NEW YORK CENTRAL. APRIL, 1905.

| No. of coaches. | Tons for coaches. | Tons for elec. loco. | Tons for steam loco. | Tons for train. | Wt. of motive power per cent. of total. |
|---|---|---|---|---|---|
| 6 | 307 | 100 | ............ | 407 | 24.5 for electric. |
| 6 | 256 | .......... | 171 | 437 | 40.4 for steam. |
| 8 | 413 | 100 | ............ | 513 | 19.5 for electric. |
| 8 | 345 | .......... | 171 | 516 | 33.3 for steam. |
| 8 | 123 | 0 | 0 | 393 | 68.7 for electric. |

This comparison between electric-locomotive- and steam-locomotive-hauled trains is favorable to the former; and the last comparison, with motor-car trains, is even more favorable to the electric train.

**Drawbar pull is well sustained at high speed** in electric locomotives. In steam locomotives it falls off rapidly as the speed increases because the fixed power of the boiler requires a reduction in the mean-effective steam pressure as the number of revolutions increases.

Drawbar pull of series-wound alternating-current and direct-current electric motors decreases much more rapidly than the speed increases and, as a result, high speeds are often accompanied by reduced work. Series motors must therefore have ample continuous capacity, also means for speed regulation, by field or potential variation; and the electric locomotive must be sufficiently heavy, to compare favorably with a steam locomotive having a large heating surface.

Statements are often made which place the drawbar pull of steam locomotives in a too unfavorable light. For example, one ordinary Mallet compound, with 150 tons on drivers and 5000 square feet of heating surface, rated 2150 h. p., shows a higher continuous drawbar pull at 15 miles per hour than three Michigan Central locomotives, each having 100 tons on drivers, and a continuous rating of 500 h. p. on forced draft.

DRAWBAR PULL OF STEAM AND ELECTRIC FREIGHT LOCOMOTIVES.

| Locomotive. | Electric. | Electric. | Electric. | Electric. | Steam. | Steam. |
|---|---|---|---|---|---|---|
| Company. | Michigan Central. | Great Northern. | Grand Trunk. | New Haven. | Great Northern. | Great Northern. |
| Type or kind. | Direct current. | Three phase. | One phase. | One phase. | Mallet compound. | Consolida. simple. |
| H.p........ | 500 | 1500 | 1140 | 1120 | 2150 | 1450 |
| Tons, total. | 100 | 115 | 132 | 135 | 252 | 156 |
| on drivers | 100 | 115 | 132 | 96 | 158 | 108 |
| D.B.pull,lbs: | | | | | | |
| starting. | 50,000 | 52,000 | 50,000 | 51,000 | 60,000 | 50,000 |
| 5 m.p.h.. | 50,000 | 52,000 | 50,000 | 50,000 | 55,000 | 44,000 |
| 10 m.p.h.. | 50,000 | 52,000 | 50,000 | 48,000 | 50,500 | 39,000 |
| 11 m.p.h.. | 48,000 | 52,000 | 50,000 | .......... | .......... | .......... |
| 12 m.p.h.. | 33,000 | 52,000 | 45,000 | 45.600 | .......... | .......... |
| 13 m.p.h.. | 24,000 | 52,000 | 40,000 | .......... | .......... | .......... |
| 14 m.p.h.. | 18,700 | 52,000 | 32,500 | .......... | .......... | .......... |
| 15 m.p.h.. | 14,500 | 47,500 | 29,500 | 40,000 | 44,500 | 33,300 |
| 16 m.p.h.. | 10,500 | 0 | 24,000 | 37,600 | .......... | .......... |
| 17 m.p.h.. | 9,500 | .......... | 22,000 | 35,500 | .......... | .......... |
| 18 m.p.h.. | 7,200 | .......... | 19,000 | 33,600 | .......... | .......... |
| 20 m.p.h.. | 5,000 | .......... | 16,000 | 29,600 | 38,000 | 26,500 |

Michigan Central, Great Northern, Grand Trunk, and New Haven electric locomotives were designed for mixed passenger and freight service. Ordinary conditions are considered, and continuous horse power.

DRAWBAR PULL OF STEAM AND ELECTRIC PASSENGER LOCOMOTIVES.

| Locomotive | Steam | Steam | Electric | Electric | Electric | Electric |
|---|---|---|---|---|---|---|
| Company. | Pennsylvania | New York Central. | New York Central. | Simplon Tunnel. | New Haven. | Pennsylvania. |
| Number...... | 5266 | 2797 | 3401 | 367 | 041 | 3977 |
| Type or kind...... | Atlantic simple. | Pacific Simple. | Direct current. | Three phase. | One phase. | Direct current. |
| H. p., cont... | 1,000 | 1570 | 1166 | 1365 | 800 | 800 |
| Tons, total | 161 | 171 | 115 | 76 | 102 | 157 |
| on drivers. | 55 | 71 | 71 | 76 | 77 | 100 |
| D.B.pull, lbs.: | | | | | | |
| starting.... | 22,000 | 33,500 | 33,500 | 26,400 | 19,200 | 69,300 |
| 10 m.p.h... | 20,000 | 33,500 | 35,000 | 26,400 | .......... | .......... |
| 15 m.p.h... | 18,500 | 32,000 | 35,000 | 26,400 | .......... | .......... |
| 16 m.p.h... | 18,000 | 31,000 | 35,000 | 21,200 | .......... | .......... |
| 20 m.p.h... | 16,000 | 30,000 | 35,000 | 21,200 | 21,000 | .......... |
| 25 m.p.h... | 13,500 | 24,000 | 35,000 | 18,050 | 17,000 | 60,000 |
| 30 m.p.h... | 12,000 | 19,500 | 35,000 | 18,050 | 13,500 | 28,000 |
| 33 m.p.h... | 11,000 | .......... | 34,000 | 12,350 | 12,000 | 21,000 |
| 35 m.p.h... | 10,500 | 16,000 | 32,000 | 12,350 | 11,000 | 44,500 |
| 40 m.p.h... | 9,000 | 14,000 | 20,500 | 12,350 | 9,000 | 29,500 |
| 45 m.p.h... | 8,300 | 12,600 | 13,000 | 9,470 | 7,400 | 21,000 |
| 60 m.p.h... | 6,200 | 10,000 | 6,000 | 0 | 4,300 | 10,000 |

## ACCELERATION RATES.

Acceleration rates commonly used with electric trains are about twice as high as those used for steam trains, and the character of the tractive effort is uniform, so that the average is raised. The speed-torque characteristics of electric locomotives, noted in the last table, show that high acceleration rates can be well maintained. Direct-current locomotives have a high tractive effort available for acceleration up one half of the rated speed; single-phase locomotive drawbar pull falls off somewhat faster; but three-phase locomotives have a small decrease in drawbar pull and acceleration rate with its lower speeds. In freight and passenger service with few stops, a high acceleration rate is not an important matter, but good suburban service demands high accelerating rates in order to attain full speed in the minimum time, to use the lowest maximum speed for a given schedule speed, to increase the coasting and to reduce the loss in braking. See "Motor-car Trains." Complete data on acceleration rates are given under "Power Required for Trains."

## SPEED AND ITS UNIFICATION.

Speeds of electric locomotives may be high, both maximum and schedule speed, for the following reasons, a to e:

a. Motion is rotary, not reciprocating; it is balanced, not unbalanced. The hammer blow of the counterbalance is eliminated. High speeds do not rack the locomotive and destroy the roadbed. The maximum speed may be increased with safety on weak roadbeds, trestles, and bridges, because of the absence of the unbalanced efforts, and because of the decreased weight on the drivers.

b. Center of gravity is lower and thus the safety of movement is increased, *provided* that (1) weights and motors are distributed, (2) weights are spring-mounted, and (3) two- or four-wheeled guiding trucks are used for high-speed work. On the other hand, a center of gravity, 8 to 10 feet above the 4.71-foot gage track, as used on high-speed steam locomotives, seems to be dangerous. (See data on center of gravity in this chapter under Electric Locomotive Design.)

c. Acceleration rates are higher by design, as noted.

d. Central stations are used to supply power to the motors. The speed of the train can be maintained with heavy loads. High drawbar pull at high speeds as used with electric power is a valuable asset.

e. Unification of train speeds becomes possible with electrically hauled freight and passenger trains. Motors which will run at a much more uniform speed, regardless of the grades and load, can be used with economy. Unification of train speed improves the efficiency and the safety of operation and the capacity of the track. The complication from non-uniformity of speed among the various trains over the same tracks is apparent, especially so on well-loaded trunk lines with varying train weights and service. Uniform speed is not a characteristic of steam locomotives: a 1600-ton train is hauled at 25 to 28 m. p. h. on the level, at 10 to 12 m. p. h. on 1.0 per cent. grade, and at 5 to 7 m. p. h. on the 2.0 per cent. grade.

Electric locomotives are able to maintain the speed with varying drawbar pull independent of the load or grade, up to the overload limits of the motors. A three-phase locomotive speed is nearly uniform, independent of the load or grades; the single-phase locomotive speed is maintained in a measure as the load increases by simply raising the transformer voltage delivered to the motor; and the direct-current locomotive speed is maintained, to some extent, by varying the field of the motor. Unification of speeds simply requires ample motor capacity, rather than motor characteristics.

The advantages of ample motor capacity, to produce a much more uniform speed, are apparent. One speed for all trains is not practical,

and the same speed for up-grade and down-grade is most undesirable from a commercial standpoint, yet greater uniformity of speed among the several trains on a division makes for simplicity of train dispatching and for the economical movement of heavy traffic on a single-track road.

**Mileage of Locomotives** is increased by:

Ample capacity in the motor and in the central station.
Rapid acceleration whenever it is practical.
Drawbar pull to maintain the speed of heavier trains.
Higher maximum and schedule speeds.
Fewer delays, from greater simplicity.
Quicker movements at terminals and switching yards.
Less time in repair shops and inspection sheds.
Time saved in washing out and cleaning boilers.
Time saved in coaling, watering, and turning.
Availability for service with minimum delay.
Unification of train speeds.
Increased motor capacity in windy, stormy, and cold weather.

"New York, New Haven & Hartford Railroad electric locomotives on the New York-Stamford electric zone cover an average of 210 miles per day, while statistics on 115 steam locomotives on the same inter-division service showed an average of 158 miles." Murray, March, 1909.

New York Central electric locomotives make fully 25 per cent. greater daily mileage than steam. Wilgus, A. S. C. E., March, 1908.

Valtellina Railway records show the annual mileage of steam locomotives is 17,213 and the annual mileage of electric locomotives is 35,120. "One electric locomotive is actually doing the work of two steam locomotives of the same capacity." Valatin.

Mileage of cars in freight service is increased by the use of electric traction. Freight cars on steam roads average but 24 miles per day, or 10 m. p. h. when moving. Steam locomotives in freight service, on account of the operating and traffic conditions, make less than 100 miles per day; but these limitations do not apply with equal force to the electric locomotives, and greater mileage per month is realized. The reason is not entirely on account of the ability to raise the schedule speed, for example from 10 m. p. h. to 17 m.p.h.; the improvement is cumulative; because overtaking trains and opposing trains do not compel the slow freight trains to take the sidings, and wait for long periods. The dispatcher would have minimum trouble and avoid many delays if all speeds were more nearly uniform. The raising of the freight train speeds, and the surety that the electric locomotives will be on time, make a radical reduction in the time wasted on sidings and increase the monthly mileage per locomotive.

Greater locomotive and car mileage per day raises the efficiency of the investment of the railroad in rolling stock, main tracks, and terminals.

## POWER DEVELOPED PER TON.

The capacity, in horse power per ton, of electric locomotives is twice as great as with steam locomotives. This is proved by comparing the tables on "Weight Factor of Electric Locomotives," given later, with the table, page 56, Chapter II, on "Horse Power per Ton of Steam Locomotives." The weight of electric trains may thus be doubled without

increasing the unit stresses from the locomotives on the bridges and railway structures. The greater horse power per ton results from:

a. Absence of coal and water tender, 25 to 30 per cent. of total.

b. Absence of furnace and boiler.

c. Greater proportion of weight on the drivers. (Many steam locomotives use a pair of wheels to support the fire box.)

d. Greater tractive effort per ton on drivers.

e. Electric motor designs, which show great power per ton. Electric locomotives are designed for the average work and they may be safely overloaded 50 per cent. for hours, or 100 per cent. temporarily. Steam locomotives are designed for the maximum work, and the limit of their capacity is in the boiler. The limit for the electric motor is the heating of the insulation on wires, and this requires several hours. Intermittent service allows cooling, and the capacity is raised in windy, cold weather.

## ADDITIONAL PHYSICAL FEATURES.

Advantages of the electric locomotive, as a machine, with reference to smoke, noise, dirt, fire, gas, mechanical efficiency, simplicity, safety and reliability, were detailed in Chapter III.

Increased capacity and good operating features may be obtained by electrification; but capacity may also be gained by grade reduction, tunnels, double tracking, elimination of curves, track elevation, block-signals, more track at terminals, more cars, and heavier steam locomotives. A broad-gage railroad management studies the initial cost, operating features, and expenses of all the physical improvements which are possible and asks for that combination which will give the greatest net return from any added investment.

## COMMERCIAL CONSIDERATIONS.

The use of electric locomotives results in important commercial advantages, which are worthy of consideration.

1. Traffic and earnings are increased as a result of ample capacity and superior power service. Items 1, 2, 3, 4 and 5 were detailed in Chapter III.
2. Car movement is facilitated to a very great extent.
3. Terminal capacity is increased—a great advantage.
4. Heavier loads are hauled, and at good speed.
5. Freight-train haulage becomes practical.
6. Maintenance and repairs are decreased.
7. Wages and time are saved.
8. Utilization of power is effective and efficient.
9. Regeneration of power is practical.
10. Water power can often be utilized.
11. Economy of fuel is obtained.
12. Cost of service is decreased.
13. Earnings from investments are enhanced.

## MAINTENANCE AND REPAIRS.

**Maintenance is decreased,** for the reasons given below:

a. Simplicity of electric motive power equipment and the smaller amount of moving apparatus reduce the wear and tear. The material and labor required for repairs is reduced to two-thirds of that for steam locomotives.

b. Depreciation is slow as a result of simplicity. In America about 450 electric locomotives are now in service, and the indications for the first 10 to 15 years' service are clear. The steam locomotive is short lived, and, after being sent to the back-shop about five times, to rebuild the boiler and furnace, the good metal and machine work are worn out; and after the engine has been in operation at real hard work for 10 years, it becomes a drag on the service. Depreciation of central station boilers, the steam or hydraulic turbines, and the electric locomotives, when combined, is relatively small per h. p. hour delivered or per ton-miles hauled.

c. Mechanical friction of electric motors, motor cars, and locomotives is relatively low, because of the reduced number of moving elements, less frictional resistance, and a 50 per cent. reduction in the dead weight.

d. Cleaning and inspection work is decreased. Electric locomotives and motor cars are inspected after each 1200- to 1500-mile run, or about every 8 days; the equipments are blown out with compressed air, are cleaned, inspected, gaged, and oiled; and without further delay are ready for service. The great saving in round-house labor is apparent. Steam locomotives, after each day's run of about 150 miles, are cooled, blown off, washed out, and cleaned; then coaled, watered, and fired up, in addition to the inspection.

e. Coal and water tenders, which must be hauled by steam locomotives, add to the cost of maintenance and repairs, but this is avoided with electric traction. The numerous water-pumping plants, the coal supply sheds, and the fuel and labor necessary to maintain them, and to supply the tenders, are dispensed with, and this work is concentrated at the central station.

f. Fewer locomotives are used with electric traction. Data from the installations made, and those under way on a larger scale, indicate clearly that three electric locomotives will replace five steam locomotives because the former have larger capacity, lower weight per h. p. developed, greater daily mileage, and fewer units in the repair shops.

**The cost of maintenance and repairs** is now considered.

Stillwell states: "The maintenance and upkeep of electric locomotives may be placed at 2 1/2 per cent. per annum, while the rate for steam locomotives is 20 per cent. per annum."

Van Alstyne, Vice-president of the American Locomotive Company, stated to the Northwest Railway Club: "After a careful consideration, I believe that the repairs and maintenance on electric locomotives could not exceed one-half of those on steam locomotives."

Pomeroy gives this comparison of maintenance costs:

| Locomotive. | Steam. | Electric. |
|---|---|---|
| Boiler | 23% | 0% |
| Running gear | 20 | 20 |
| Machinery | 30 | 15 |
| Lagging and painting | 12 | 5 |
| Smoke box | 5 | 0 |
| Coal and water tender | 13 | 0 |
| Total | 100 | 40 |

New York Central saved 20 per cent. net, in repairs and fixed charges. The average cost of interest, depreciation, repairs, inspection, and handling was about $4750 per year for steam locomotives and $3800 per year for electric locomotives, according to Wilgus.

New Haven steam locomotive records per locomotive-mile are: Passenger locomotive maintenance, $.017; repairs, $.039; total, $.056. Freight locomotives, maintenance, .014; repairs, .067; total, .081. Its electric locomotive maintenance and repairs have been high because the installation, made in 1907, was of a radical and untried character; but the maintenance and repair expense is now decreasing rapidly.

Grand Trunk Railway reports in effect that the maintenance cost for steam locomotives at the Port Huron tunnel, where the service is heavy and severe, averaged 13.6 cents per locomotive-mile in 1908; while that of the electric locomotive was 4.3 cents per locomotive-mile. Maintenance and repairs for 1909 were 55 per cent. of the steam cost.

**Maintenance and repair records** of locomotives are not easily obtained. Accounts show a general uniformity, but rules of each railroad govern. Cost depends upon the kind of water used, the class of enginemen employed, the thoroness and efficiency of the shop work, which in turn may be affected by labor troubles; the condition of the roadbed, the train loading, the policy of the company regarding improvements, and safety in train service. After a wreck, locomotive repairs may be charged to accidents. Renewals of old locomotives may be charged to equipment.

Passenger locomotives in steam service require general repairs about every 100,000 miles; freight locomotives, every 70,000 miles; yet this depends on the service, not on the miles. Records should extend over many years and, should be fair, should be based on the ton-miles hauled.

## MAINTENANCE AND REPAIR COSTS PER ELECTRIC LOCOMOTIVE MILE.

### TABLE I.

| Name of railroad. | Cost per mile; cents. | Authorities and reference quoted. |
|---|---|---|
| Buffalo & Lockport | 0.79 | Stillwell, A.I.E.E., Jan. 1907, p. 62. |
| Baltimore & Ohio | 6.00 | Muhlfield, S.R.J., Feb. 24, 1906, p. 307. |
| St. Louis & Suburban | 0.60 | G.E. advertisement. |
| New York Central | 1.60 | G.E., first 50,000-mile test. |
| | 1.26 | G.E., 100,000-mile test. |
| | 4.60 | Interstate Commerce report, 1908. |
| New York, New Haven & H. | 5.00 | A.I.E.E., Jan. 25, 1907, p. 150. |
| Grand Trunk | 7.46 | 1909 records by Kirker. |
| | 4.30 | 1908 Elec. Review, March 6, 1909. |
| Hoboken Shore | 1.50 | Bevoise. |
| Illinois Traction | 2.24 | 1910, approximate. |
| Paris-Orleans | 2.30 | Dubois, S.R.J., May 20, 1905. |
| Paris-Versailles | 5.00 | Dubois, S.R.J., May 20, 1905. |
| Paris-Metropolitan | 1.54 | Dubois, S.R.J., May 20, 1905. |
| Valtellina | 1.38 | Cserhati, S.R.J., Aug. 26, 1905, p. 303. |
| | 1.80 | Stillwell, A.I.E.E. Jan. 1907, p. 62. |

### TABLE II.

| Name of railroad. | No. of locos. | Locomotive repairs and renewals. | Annual locomotive mileage. | Cost per mile; cents. | Data for year. |
|---|---|---|---|---|---|
| Baltimore & Ohio | 10 | $16,475 | 200 000 | 8.2 | 1908 |
| New York, New Haven & H. | 21 | 27,660 | 500,000 | 5.5 | 1908 |
| New York Central | 35 | 45,888 | 1,000,000 | 4.6 | 1908 |
| Baltimore & Ohio | 10 | 7,775 | 170,000 | 4.5 | 1909 |
| New York, New Haven & H. | 41 | 256,704 | 2,000,000 | 12.8 | 1909 |
| New York Central | 47 | 31,319 | 1,000,000 | 3.1 | 1909 |
| Baltimore & Ohio | 12 | ............ | 180,000 | .......... | 1910 |
| New York, New Haven & H. | 41 | 140,983 | 2,136,500 | 6.6 | 1910 |
| New York Central | 47 | ............ | 1,100,000 | .......... | 1910 |
| Great Northern | 4 | 30,534 | 50,150 | 5.00 | 1910 |

Repair and renewal data are from Interstate Commerce Commission Report for 1908, p. 181; for 1909, p. 137; annual reports of railroad companies, and other sources.

See maintenance data for Steam Locomotives, and for Motor-car Trains.

Some railroads believe in wearing locomotives out, as fast as possible, in hauling trains, and few extra locomotives are kept in service; locomotives are continually replaced with more modern machines. This plan gives better results than to operate locomotives which are 15 years old.

In studying maintenance cost, care should be taken to get the basis of the book-keeping and all comparable data on service. Complete information is seldom obtained.

## WAGES.

**Wages and time are saved** with electric service.

Locomotive and roundhouse work is decreased.

Rate of wages paid is reduced.

Firemen are not required.

Automatic devices and meters increase safety.

Locomotive mileage is greater; shopping is less.

Heavier trains require less labor per mile run.

Double heading does not require duplication of men.

Time is utilized efficiently in actual running.

Service is more continuous with electric locomotives.

Less work and time are required for efficient switching.

Labor is more efficient, and is of a better class.

Speed of freight trains on grades is higher.

These points have been detailed in Chapter III, under the heading, "Decreased Operating Expenses—Wages."

Grand Trunk Railway records show a saving, following the St. Clair tunnel electrification, of 15 and 23 per cent. in the wages paid to locomotive crews and train crews respectively.

New York Central uses one motorman for a 6- to 10-car multiple-unit train in place of an engineman and a fireman on a steam locomotive.

Metropolitan and Metropolitan District Railway, London, reduced the wages of drivers 20 to 25 per cent. with the advent of electric traction.

Lancashire and Yorkshire electric express trains have only two trainmen, one driver and one conductor; while the heavier local trains require one driver, one conductor, and one rear man.

In England, Germany, and France the same general fact is noted: Electric train service requires less wages per train mile.

## ECONOMY OF POWER.

**Utilization of the power** produced at the central station is effective and efficient when electric locomotives are used, as explained in Chapter III, under "Decreased Operating Expenses."

**Regeneration of power** which effects an economy in operation is considered under "Power Required for Trains."

**Water powers** can be used. See "Water Power Plants."

## ECONOMY OF FUEL.

Steam locomotives burn approximately the following coal per 1000 ton-miles: Switching, 1300; suburban, 500; ordinary passenger, 250; ordinary freight, 150. The pounds of coal per i. h. p. hr. approximate: Suburban, 6.75; ordinary passenger, 4.0; ordinary freight locomotives, 3.0; and modern steam power plants, 2.0 pounds. See page 82.

Electric traction, with energy supplied from a central station, is now compared with the steam locomotive:

FUEL SAVING WITH ELECTRIC TRACTION.

| | | | |
|---|---|---|---|
| Fuel of cheaper grades, saves | 30 | to | 10% |
| Furnace and boiler economy | 35 | to | 30 |
| Radiation and condensation | 20 | to | 10 |
| Cylinder or steam economy | 30 | to | 25 |
| Friction of mechanism | 12 | to | 6 |
| Total saving (not the sum), | | | 60 |
| Generator and transformer loss | 5 | to | 8 |
| Transmission and contact line | 2 | to | 8 |
| Transformation | 3 | to | 6 |
| Motor and control | 10 | to | 6 |
| Total loss approximates | | | 25 |
| **Net saving** in fuel (1.00 – .60) x 1.25 = | | | 50 |

The fuel savings include those due to stoker in furnace, water-tube boilers, superheaters, feed water heater, less radiation, less stand-by and banked-fire losses, gain at poppet valves, greater expansion of steam in turbines, condensing operation, and power production on a large scale.

Economy of fuel, which is naturally expected with electric traction, was considered in Chapter III under "Decreased Operating Expense."

Efficiency of simple steam locomotives was explained in Chapter II. Efficiency is lowest with the late cut-off required on grades, and in starting or accelerating a train. The fuel consumed by steam locomotives while standing idle, or waiting at a meeting point, is a large percentage of the total. Each locomotive, without doing any useful work, may burn 300 to 800 pounds of coal per hour or 15 to 25 tons per month. Almost all of this is saved in electric traction.

The superior efficiency of a modern steam power plant is evident. Power can ordinarily be generated, delivered, and applied in a wholesale manner more effectively than by an individual steam locomotive. Modern power plants employ high-grade engineers to manage the furnaces and stokers and to burn cheapest fuels, under clean water-tube boilers. Efficient steam turbines, minimum internal losses, ample water for condensation, feed-water heaters, and economisers are utilized. Losses in electric generators, lines, and transformers are compensated by the decreased friction and the lighter weight of the electric locomotive.

The saving of 50 per cent. of the cost of fuel is realized. Fuel cost is 11 per cent. of the operating expenses of steam railroads and is thus an item affecting economical transportation.

New York Central Railroad furnishes data on fuel saving, of interest. "For road tests, steam locomotives require 1.22 pounds of coal per car-ton-mile; electric locomotives, after allowing for power plant charges and expenses at 2.6 cents per kw. hr., save 28 per cent. of the fuel item." It formerly paid for coal, used on steam locomotives in terminal service, \$5.00 per long ton, and in road service, \$3.50; while at its Mt. Morris power station, coal with equal B.t.u. costs less than \$3.05 per ton.

Pennsylvania Railroad's electric power station in Long Island City burns low-grade screenings efficiently on modern stokers.

Grand Trunk Railway, for its Port Huron tunnel, formerly used anthracite coal under its steam locomotives. These results are reported:

"The fuel bill for steam locomotives during the last six months in steam service averaged \$4,956 a month. The fuel bill for the first six months of electric service averaged \$1,152.60 a month. Hard coal, costing \$6 a ton, was used on the steam locomotives. Bituminous coal, costing \$2 per ton, is used in the power station." Kirker, in Elec. Review, March 6, 1909, p. 423. The 1909 records, with cheaper grades of coal, give the fuel cost as 39 per cent. of that under steam operation.

South Side Elevated Railroad, Chicago, in 1898 operated modern Baldwin compound locomotives, weighing 28 tons, to haul 5-car trains. The road was electrified and the saving in coal was \$500 per day.

Manhattan Elevated Railroad under most favorable conditions with its steam locomotives used 1 pound of coal to produce 2.23 ton-miles, or 1.50 ton-miles when the weight of the cars only was considered. Four years later, when electricity was used exclusively, 1 pound of coal burned at the power house produced 3.83 ton-miles. Therefore the ratio of ton-mileage per pound of coal in favor of electric operation was 2.57 to 1; or, since under electrical operation the average speed was 2 m.p.h. greater, the ratio of ton-mileage per pound of coal was 3 to 1. This saving in coal consumption is 1,000,000 tons of coal per annum. (Stillwell.)

New York, New Haven & Hartford Railroad tests, as reported by Murray, electrical engineer, to A. I. E. E., Jan. 25, 1907, p. 147, show the coal and the ton-miles required during 18 months for the run between New York and New Haven, in steam railroad service, were as follows:

| Kind of railroad service. | Lb. of coal per average i.h.p. hr. | Lb. of coal per revenue ton-mile. | Average tons per train. |
|---|---|---|---|
| Passenger-express | 4.06 to 4.37 | 0.194 | 527 |
| Passenger-express-local | 4.68 to 4.61 | 0.335 | 314 |
| Freight service | not taken | 0.169 | 931 |

Tests were made in August when track and temperature favored good results. Murray estimated, in January, 1907, that the saving of coal with electric traction

would be 40 per cent. Two years later he wrote: "By far the most interesting feature of the investigation, which has been continued, is now to find that, by actual operation, the saving in coal for electric passenger operation, as against steam, for the same service, is just 50 per cent."

Lancashire & Yorkshire Railway, of England, J. A. F. Aspinwall, General Manager, has recently reported that on its Liverpool-Southport branch, 37 miles, which now uses electric traction, the saving in coal per train-mile is 48 per cent.

"Mersey Tunnel Railway of England, with steam traction, required 1 ton of coal costing $4.00 per ton to move 1 ton of train load 2.21 miles at 17.75 miles per hour; while with electric traction, it required 1 ton of coal costing only $2.18 per ton to move 1 ton of train load 2.29 miles at an average speed of 22.25 miles per hour." The net saving was 55 per cent. J. Shaw, B. I. C. E., November, 1909.

**Cost of service per ton-mile is reduced** because electric locomotive units haul faster and heavier trains in a given time; save in fuel, labor, and maintenance; utilize the cheapest coal, or water powers; decrease the non-revenue-bearing ton-miles of locomotives; and utilize the energy produced to great advantage, in common service or on mountain grades.

**Earnings from investments are enhanced** when the tracks, equipment, and rolling stock are used efficiently; when more work is done in a given time; and when the ton-mileage is increased by an efficient motive power. The increased load, the increased speed, the shorter delays, and the greater mileage of locomotives and cars, also save in investments which would otherwise be required in an ordinary single-track road, at bridges, tunnels, grades, and congested terminals.

An increased investment is required with electric traction; but it is evident that if twice the horse power can be utilized efficiently on a given length of line, to double the work or the receipts from the same track, and if this can be done with an extra investment of a small part of the total cost of the road, the business proposition is worth consideration.

Increased efficiency and capacity, and other physical advantages of electric traction, result in a financial advantage; otherwise electric power should never receive consideration for important railway service.

## ADVANTAGES OF LOCOMOTIVES OVER MOTOR-CAR TRAINS.

The electric locomotive has some advantages in train haulage not possessed by motor cars.

**Independent units** are obtained by the use of locomotives. The division of the equipment between the locomotives and the coaches facilitates different classes of care and inspection. Locomotive motors, in heavy service, after running several hours on an extreme overload, may be cooled by forced draft; or another locomotive may be utilized. With motor-car trains this is not so practical.

**Locomotives are used as freight cars** by the Paris-Orleans Railway, by the North-Eastern of England, and by American interurban roads.

Such locomotives, of the baggage-car type, weighing 20 to 60 tons, are loaded with express, mail, merchandise, perishable goods, etc., and haul freight cars or passenger coaches.

Locomotives are needed for thru passenger and freight-car haulage.

**Danger to passengers** is decreased when the motors are placed on the locomotive only. It is more difficult to avoid some of the dangers of an electric shock, from leakage, fire, or short circuit, whenever high voltages required in railroading pass thru steel conduit wiring under each electric car of the train. In case of a head-end collision, the danger is decreased when a locomotive, or a steel baggage motor car, is at the head of a train.

**High voltages can be used** on the field windings. Three-phase, 3000-volt locomotive motors do not require a step-down transformer, and the locomotive weight is greatly reduced. Leonard's motor-generator locomotive plan, which embraces a high-voltage, single-phase, 60-, 25-, or 15-cycle, high-speed motor, driving a direct-current generator, which in turn supplies current at varying voltages to 600-volt direct-current motors, may be used. High voltages are not practical with motor-car trains, without the use of step-down transformers.

**Designs of motors** for locomotive service are better, because the space between or above large drivers, or above the frames, may be used. Insulation of motors can be used more liberally or more advantageously.

**Cost of equipment** is reduced with locomotives. Larger motors are used, the installation is concentrated, and few changes are required in existing passenger and freight cars.

**Maintenance of equipment** is lower than on motor-car trains Fewer motors are placed on the locomotive trucks or frames; cleanliness is obtained, and insulation is not easily damaged by moisture. Motor equipment is more accessible and can receive better supervision and inspection to prolong its life. The number of parts is less with the larger motors and thus the cost of repairs and inspection of motors and controllers is less. The total maintenance cost of motors of locomotives per ton-mile or per passenger-mile hauled is less than 60 per cent. of the maintenance cost of motors on cars.

## ELECTRIC LOCOMOTIVE DESIGN.

Modern electric locomotives for railroad trains represent the culmination of numerous efforts in design, beginning even before the pioneer days at Baltimore, in 1895. A general review will assist in gaging the value of the work done and will classify some of the features which follow in "Technical Descriptions of Electric Locomotives."

Up to the year 1905, there had been few attempts at standardization of frames or of mechanical motion, for either freight or passenger service. Each new locomotive had special features in design; but almost every

conceivable wheel arrangement, driving mechanism, and general proportion had been tried out, in an effort to create ideal types.

It is a notable fact, that, following the adoption of electric locomotive power by the leading steam railroads, since 1906, the character of the construction and the mechanical arrangement of the electric locomotive frame, truck, wheels, etc., have been rapidly improved, and standardized to some extent.

Electric locomotives are energy-collecting and transmitting machines, as contrasted with steam locomotives which are prime movers, that is, energy-generating machines, a fundamental difference which affects operation and design. This inherent difference is such that steam practice and experience cannot be utilized. The boiler, furnace, and fuel and water supply, and the reciprocating strains are absent.

Designs of electric machines generally embrace a box-shaped symmetrical cab or superstructure, double-end operation, flexible frames, light-weight plate and rolled-steel shapes in side framing, transmission of forces and strains of freight locomotives thru articulated trucks, lower center of gravity, geared and direct connection of motive power to axles, and, except in Pennsylvania type locomotives, journals outside of the driving wheels. In braking, the energy of rotation stored up in large heavy motors require more powerful brakes, larger brake shoes, and tires to dissipate the stored energy. In electric freight locomotives ballast is often added to get the desired tractional adhesion.

Electric locomotive design, as a matter of prime importance, embraces a machine which is capable of performing the same kind of service which the modern steam locomotive now performs; which exceeds the steam locomotive in its power capacity; and which is adapted for branch lines, light passenger and heavy freight service. George Westinghouse, 1910.

**Mistakes made in the design** of early electric locomotives were caused by lack of experience, by not appreciating the problems, by a desire for simplicity, and by unsatisfactory compromises between steam and electric locomotive designers.

1. Low centers of gravity were used, which at high speed caused the curves to be slewed.

2. Heavy dead weights were not spring-mounted, and the track was destroyed by the intensity of the blows at low joints, badly aligned spots, and special work at crossings and switches. Side springs were not used between motors and frames to ease the blow on the curves. Gearless motors increased the cost of track maintenance, when they were not spring-mounted.

3. High speeds were attempted without locomotive guiding truck wheels. Leading trucks are necessary and they must carry a considerable vertical load (20,000 to 28,000 pounds per axle), otherwise high-speed running becomes hard and dangerous. Rigid frames and symmetrical disposition produced severe nosing effects.

4. Concentration of power on a short driver-wheel base produced strains with

great intensity of pressure and with suddenness of application. Electric locomotives pitched and rolled, with the best track alignment.

5. Bearings on motors were not long enough and, with the added heat radiated by the motor, they ran hot.

6. Motors were not accessible for inspection, nor easily removed from the locomotive, for overhauling and repairs.

7. Ratings of motors on the one-hour basis were misleading and deceiving; and ratings based on continuous performance or for many hours' run were not known. Trouble and disappointment followed until some of these things related to design were understood and corrected.

**Types of locomotives** are classified with reference to trucks:

1. Rigid wheel base types (a) without leading and trailing trucks, (b) with leading and trailing trucks. Examples: Grand Trunk; New York Central.

2. Separated bogie truck types (a) symmetrical and (b) unsymmetrical, the trucks being connected thru the upper frames. Examples: New Haven, passenger; Great Northern.

3. Articulated trucks, wherein two sections are hinged back to back. Examples: Pennsylvania; Michigan Central.

Other classifications can be made with reference to motor mounting, the mechanical transmission of power between the motors and driving axles, etc.

Mr. George Gibbs tested many types of electric locomotives for the Pennsylvania Railroad Company in 1909, to determine the relative riding qualities of high-speed locomotives. He states:

"It was found that all types of locomotives were practically steady at speeds under 40 miles per hour, but that above this speed marked differences appeared; that the steadiest riding machines were those with (a) high center of gravity and (b) with long and unsymmetrical wheel base. In other words, that the nearer steam locomotive design is approached in wheel arrangement, distribution of weight, height of center of gravity, and ratio of spring-borne to under-spring weight, the less the side pressures registered on the rail head. In addition to the excessive side pressures on the rail head, due to the oscillation and "nosing" of a low center of gravity machine, abnormal track effects may be caused by the vertical pounding due to a large non-spring-borne motor weight, or to weights with imperfect spring cushion. A remedy for all of these defects appears to mean a combination of driving and carrying wheels, an unsymmetrically disposed wheel base and the setting of the motors on the main frames above the axles." *Electric Locomotives.* International Railway Congress, 1910; Ry. Age Gazette, March 25, 1910, p. 830; E. R. J., June 3, 1911, p. 961.

Mr. Sprague thinks that nosing on New York Central, and other electric locomotives, is caused by the driver treads, which are cones, and these try alternately to mount or ride on the flange side of the tread, producing a swinging or lateral motion. These vibrations are dampened by time-element springs, and the blows of the wheels are attenuated.

Mr. Sprague states emphatically that the hard riding qualities of the New York Central locomotives are not due to their low center of gravity and symmetrical base, but rather to the absence of sufficient resistance in the pony-truck centering springs to prevent nosing. A. I. E. E., July 1, 1910.

**Center of gravity** of electric locomotives is usually low.

CENTER OF GRAVITY OF ELECTRIC LOCOMOTIVES.

| Name of railroad. | Kind of service. | Speed in m.p.h. | Year first used. | Wt. in tons. | Diam. of Arm. | Diam. of Drivers. | Armature center above rail. | Center of gravity above rail. |
|---|---|---|---|---|---|---|---|---|
| Baltimore & Ohio... | Passenger..... | 25 | 1895 | 96 | ....... | 62″ | 31.0″ | 43″ |
| | Freight....... | 25 | 1903 | 80 | ....... | 42 | 22.1 | 40 |
| | Freight....... | 26 | 1910 | 92 | 25.0 | 50 | 26.1 | 43 |
| New York Central.. | Passenger..... | 60 | 1906 | 95 | 29.0 | 44 | 22.0 | 44 |
| | Passenger..... | 60 | 1909 | 115 | 29.0 | 44 | 22.0 | 40 |
| New Haven....... | Passenger..... | 60 | 1907 | 96 | 39.5 | 62 | 31.0 | 53 |
| | Passenger..... | 60 | 1909 | 102 | 39.5 | 62 | 31.0 | 51 |
| | Fgt. geared ... | 35 | 1909 | 140 | 39.5 | 63 | 63.7 | .......... |
| | Fgt. side-rod.. | 35 | 1910 | 135 | 76.0 | 57 | 91.0 | .......... |
| Valtellina, 1904 .... | Passenger..... | 38 | 1904 | 69 | 68.0 | 59 | 41.0 | 53 |
| Pennsylvania 10,001 | Experimental . | 40 | 1905 | 97 | ....... | 56 | 28.0 | 42 |
| 10,003 | Experimental . | 40 | 1909 | 100 | ....... | 72 | 36.0 | 55 |
| Pennsylvania....... | Passenger..... | 66 | 1910 | 157 | 56.0 | 72 | 93.5 | 64 |
| Grand Trunk....... | All trains...... | 25 | 1908 | 66 | 30.0 | 62 | 31.0 | 51 |
| Great Northern..... | All trains ..... | 15 | 1909 | 115 | 35.75 | 60 | 30.0 | 60 |
| Michigan Central ... | All trains ..... | 22 | 1909 | 100 | 25.0 | 48 | 25.1 | 42 |
| Paris-Orleans ..... | Passenger..... | 30 | 1900 | 55 | 23.5 | 49 | 24.5 | ......... |

The tendency is to use larger driver diameters to get a longer life from the tires. Steam locomotives in passenger service have a center of gravity about 72 inches above the rails.

No diversity of opinion would exist regarding the advantage of a low center of gravity, nor would the track maintenance be higher, with a low center of gravity, *provided* (1) The track and rails were level tangents; (2) the weight and power of the locomotive were well distributed, not concentrated; (3) the two or four guiding wheels were not omitted, and (4) the armature and motor frame weights were not rigidly mounted. A four-wheeled leading truck turns on its pivot and instead of attempting to at once turn the mass of the locomotive, the forward wheels act as a guide, with the rear as a fulcrum. Wheels are not rigidly mounted in bearings, but they traverse slightly, in any direction, without moving the whole mass of the locomotive.

Electric machines with low center of gravity have less tendency to topple over, but have greater resultant side thrusts on the rail head. Electric locomotives in high-speed service must be properly guided, and must have a high center of gravity, for service over ordinary irregular track. The locomotive then heels over at the curves and increases the vertical pressure on the rails, rather than the side thrust.

The nosing of the motor cars is held to be small because the product of the lever arm about the center pin of the rear truck, and the mass on front of the rear truck make a small moment to produce lateral components or harmonic vibrations, compared with the moment arm of the car body.

MECHANICAL DATA AND WEIGHT OF ELECTRIC LOCOMOTIVES.

| Name of railroad. | Year built. | 1-hour. h.p. | Wheel order. | Tons motors. | Tons total. | Tons on drivers. | Pounds per driv. axle |
|---|---|---|---|---|---|---|---|
| Baltimore & Ohio..... | 1895 | 1080 | OO–OO | ........ | 96 | 96 | 48,000 |
| | 1903 | 800 | OO–OO | 22.0 | 80 | 80 | 40,000 |
| | 1910 | 1100 | OO–OO | 21.0 | 92 | 92 | 46,000 |
| New York Central..... | 1906 | 2200 | oOOOOo | 25.0 | 95 | 68 | 33,500 |
| | 1909 | 2200 | ooOOOOoo | 25.0 | 115 | 71 | 35,500 |
| Pennsylvania......... | 1910 | 2500 | ooOO–OOoo | 43.0 | 157 | 100 | 50,000 |
| Michigan Central...... | 1909 | 1100 | OO–OO | 22.3 | 100 | 100 | 50,000 |
| Simplon.............. | 1907 | 1100 | oOOOo | 25.0 | 70 | 50 | 33,333 |
| | 1909 | 1700 | OOOO | 27.0 | 76 | 76 | 38,000 |
| Valtellina............ | 1902 | 600 | OO–OO | 22.0 | 52 | 52 | 26,000 |
| | 1904 | 1200 | oOOOo | 27.5 | 69 | 47 | 31,340 |
| | 1906 | 1500 | oOOOo | 27.3 | 69 | 47 | 31,340 |
| Giovi................ | 1909 | 1980 | OOOOO | 27.0 | 67 | 67 | 26,800 |
| Great Northern....... | 1909 | 1700 | OO–OO | 30.0 | 115 | 115 | 57,500 |
| Grand Trunk.......... | 1908 | 720 | OOO | 23.5 | 66 | 66 | 44,000 |
| Spokane & Inland..... | 1908 | 670 | OO–OO | ........ | 72 | 72 | 36,000 |
| New Haven: | | | | | | | |
| Passenger, 020...... | 1907 | 960 | OO–OO | 33.4 | 96 | 96 | 48,000 |
| Passenger, 041...... | 1908 | 960 | oOO–OOo | 33.4 | 102 | 77 | 38,500 |
| Freight, 071...... | 1909 | 1260 | oOO–OOo | 40.0 | 140 | 96 | 48,000 |
| Freight, 070...... | 1910 | 1350 | oOO–OOo | 41.6 | 135 | 92 | 46,000 |
| Freight, 069...... | 1911 | 1396 | ooOOOOoo | ........ | 116 | .......... | .......... |
| Switcher, 0200..... | 1911 | 600 | OO–OO | 16.0 | 80 | 80 | 40,000 |
| Oranienburg.......... | 1906 | 1050 | OO–OO | ........ | 66 | 66 | 33,000 |
| Baden State.......... | 1910 | 1050 | oOOOo | ........ | 71 | .......... | .......... |
| Bernese Alps, A.E.G... | 1910 | 1600 | oOO–OOo | 30.0 | 103 | 75 | 37,500 |
| Oer. | 1911 | 2000 | OOO–OOO | 21.0 | 97 | 97 | 33,600 |
| French Southern...... | 1910 | 1600 | oOOOo | 30.0 | 88 | 61 | 40,600 |
| Prussian State ....... | 1911 | 800 | OOOO | ........ | 64 | 64 | 36,500 |
| Swedish State........ | 1911 | 2000 | OOO–OOO | ........ | 110 | 110 | 36,666 |

The weight per driver axle for high-speed electric locomotive service should not exceed 40,000 with ordinary track and 50,000 with very good rail, bridges, and road bed—even in slow-speed service. The lower weight per axle greatly decreases the cost of track maintenance. European practice indicates 35,000 to 40,000 pounds per axle. German government has specified a maximum of 36,000 pounds per axle.

Dead weight per driving axle of New York Central electric locomotives is 13,000 pounds; of Michigan Central is 14,000 pounds; of Great Northern is 18,300 pounds.

MECHANICAL DATA ON TRUCKS OF ELECTRIC LOCOMOTIVES.

| Name of railroad. | 1-Hour h.p. | Tons total. | Wheel base. | | Lbs. per ft total base. |
|---|---|---|---|---|---|
| | | | Rigid. | Total. | |
| Baltimore & Ohio | 1080 | 96 | 6′–10″ | 23′–2 3/4″ | 8,300 |
| | 800 | 80 | 14 –6 3/4 | 14–6 3/4 | 10,990 |
| | | 160 | 14 –6 3/4 | 44 –2 3/4 | 7,240 |
| | 1100 | 92 | 9 –6 | 27 –6 | 6,700 |
| New York Central | 2200 | 115 | 13 –0 | 36 –0 | 6,390 |
| Pennsylvania | 2500 | 157 | 7 –2 | 55 –11 | 5,610 |
| Michigan Central | 1100 | 100 | 9 –6 | 27 –6 | 7,275 |
| St. Louis & Belleville | 640 | 50 | 6 –0 | 20 –6 | 4,900 |
| Buffalo & Lockport | 640 | 38 | 6 –0 | 13 –0 | 5,840 |
| Hoboken Shore | 400 | 64 | ....... | .............. | .......... |
| Illinois Traction | 800 | 60 | 7 –2 | 26 –2 | 4,550 |
| Paris-Orleans | 1000 | 55 | 7 –10 | 23 –10 | 4,520 |
| Milan-Gallarate | 640 | 37 | 6 –10 | 21 –4 | 3,640 |
| Simplon | 1100 | 70 | 6 –9 | 31 –10 | 4,400 |
| | 1700 | 76 | 5 –7 | 26 –3 | 5,800 |
| Valtellina | 600 | 52 | 6 –7 | 21 –9 | 4,775 |
| | 1200 | 68 | 16 –1 | 31 –10 | 4,275 |
| | 1500 | 69 | 15 –5 | 31 –2 | 4,400 |
| Giovi | 1980 | 67 | 10 –1 | 20 –2 | 6,150 |
| Great Northern | 1700 | 115 | 11 –0 | 31 –9 | 7,250 |
| Grand Trunk | 720 | 66 | 16 –0 | 16 –0 | 8,250 |
| Spokane | 680 | 72 | ....... | .............. | .......... |
| New Haven 041 | 960 | 102 | 8 –0 | 30 –10 | 6,620 |
| 071 | 1260 | 140 | 7 –0 | 38 –6 | 7,275 |
| 070 | 1350 | 135 | 8 –0 | 43 –6 | 6,210 |
| 069 | 1396 | 116 | 11 –0 | 39 –0 | 6,000 |
| 0200 | 600 | 80 | 8 –0 | 23 –6 | 6,810 |
| Oranienburg | 1050 | 66 | 10 –10 | 31 –5 | 4,200 |
| Baden State | 1050 | 71 | 11 –6 | 31 –2 | 4,550 |
| French Southern | 1600 | 88 | 11 –10 | 31 –6 | 5,650 |
| Bernese Alps, A.E.G | 1600 | 103 | 9 –11 | 42 –2 | 4,880 |
| Bernese Alps, Oerlikon | 2000 | 97 | 13 –5 | 36 –5 | 5,310 |

## WEIGHT-FACTOR OF DIRECT-CURRENT LOCOMOTIVES IN RAILROAD SERVICE.

| Name of railroad. | Name of builder. | Kind of service. | Speed m.p.h. | 1-hr. h.p. | Wt., tons. | 1-hr. h.p. per ton. | Cont. h.p. | Cont. h.p. per ton. |
|---|---|---|---|---|---|---|---|---|
| Baltimore & Ohio | G.E. | Passenger | 16 | 1080 | 96 | 11.3 | | |
| Baltimore & Ohio | G.E. | Freight | 9 | 800 | 80 | 10.0 | | |
| Baltimore & Ohio | G.E. | Freight | 26 | 1100 | 92 | 12.0 | 460 | 5.0 |
| New York Central | G.E. | Terminal | 60 | 2200 | 115 | 19.1 | 1000 | 9.0 |
| Pennsylvania | G.E. | Terminal | 60 | 2500 | 157 | 15.9 | 1600 | 9.8 |
| Michigan Central | G.E. | Tunnel | 10 | 1100 | 100 | 11.0 | 475 | 4.7 |
| Bush Terminal | G.E. | Switcher | 10 | 360 | 50 | 7.2 | | |
| Hoboken Shore | West. | Switcher | 6 | 400 | 60 | 6.6 | | |
| Illinois Traction | G.E. | Freight | 30 | 960 | 60 | 16.0 | | |
| Metropolitan | T.H. | Terminal | | 800 | 51 | 15.7 | | |
| Paris-Orleans | T.H. | Terminal | 30 | 1000 | 51 | 16.4 | | |

Weight factor does not refer to efficiency of design. A motor with slow peripheral speed, or a small switcher, or a slow-speed locomotive cannot be so efficient in pounds per ton as one for high speed. Most locomotives for freight service are ballasted, or steel is used liberally in the design, to get maximum adhesion for traction.

The speed is not at the 1-hour or continuous h.p. but at the rated loads, or trailing tons on the ruling grade, given in a succeeding table on driver diameters.

R. p. m. = m. p. h. x gear ratio x 336/diameter of drivers in inches.

Data on peripheral speed of motor armatures is given in Chapter V.

The tendency to rate railroad locomotive motors on the continuous basis, not on the 1-hour basis, is recognized.

## WEIGHT FACTOR OF THREE-PHASE LOCOMOTIVES IN RAILROAD SERVICE.

| Name of railroad. | Name of builder. | No. of cycles. | Kind of service. | Speed m.p.h. | 1-hr. h.p. | Wt., tons. | 1-hr. h.p. per ton. | Cont. h.p. | Cont. h.p. per ton. |
|---|---|---|---|---|---|---|---|---|---|
| Valtellina | Ganz | 15 | Freight | 19 | 600 | 52 | 11.6 | | |
| Valtellina | Ganz | 15 | Passenger | 38 | 1200 | 69 | 17.4 | | |
| Valtellina | Ganz | 15 | Passenger | 40 | 1500 | 69 | 21.7 | | |
| Giovi-Savona | West. | 16 | Freight | 28 | 1980 | 67 | 29.5 | 1440 | 21.5 |
| Santa Fe | Brown | 16 | Freight | 16 | 320 | 30 | 10.6 | | |
| Simplon | Brown | 16 | Freight | 43 | 1100 | 70 | 15.7 | | |
| Simplon | Brown | 16 | Mixed | 43 | 1700 | 76 | 22.4 | | |
| Great Northern | Gen. Elec. | 25 | Mixed | 15 | 1700 | 115 | 14.8 | 1500 | 13.0 |

European locomotives have exceedingly light frames, suitable for medium speeds. American locomotives haul 3 to 4 times the tonnage per train. Tons of 2000 pounds. Great Northern continuous rating is on forced draft.

## WEIGHT FACTOR OF SINGLE-PHASE LOCOMOTIVES IN RAILROAD SERVICE.

| Name of railroad. | Name of builder. | No. of cycles. | Kind of service. | Speed m.p.h. | 1-hr. h.p. | Wt. tons. | 1-hr. h.p. per ton. | Cont. h.p. | Cont.h.p. per ton. |
|---|---|---|---|---|---|---|---|---|---|
| West. Interworks | West. . . | 25 | Freight. . . | 40 | 675 | 68 | 9.9 | . . . . . . | . . . . . . . . |
| Windsor, Essex & Lake Shore. | West. . . | 25 | Freight. . . | 40 | 400 | 35 | 11.4 | . . . . . . | . . . . . . . . |
| Spokane & I. E. . | West. . . | 25 | Freight. . . | 25 | 500 | 52 | 9.6 | 385 | 7.4 |
| Spokane & I. E. . | West. . . | 25 | Freight. . . | 15 | 680 | 72 | 9.5 | 560 | 7.8 |
| Grand Trunk. . . . | West. . . | 25 | Freight. . . | 25 | 720 | 66 | 10.9 | 570 | 8.6 |
| Rock Island. . . . . | West. . . | 25 | Freight. . . | 40 | 500 | 50 | 10.0 | . . . . . . | . . . . . . . . |
| New Haven 041. | West. . . | 25 | Passenger. | 70 | 960 | 102 | 9.6 | 800 | 8.0 |
| 069. | West. . . | 25 | Freight. . . | 35 | 1396 | 116 | 12.0 | . . . . . . | . . . . . . . . |
| 070. | West. . . | 25 | Freight. . . | 35 | 1260 | 135 | 9.3 | 1120 | 8.3 |
| 071. | West. . . | 25 | Freight. . . | 35 | 1350 | 140 | 9.6 | 1130 | 8.0 |
| 0200. | West. . . | 25 | Switcher . | . . . . . . . . . | 600 | 80 | 7.5 | 450 | 5.7 |
| Boston & Maine. | West. . . | 25 | Freight . . | 30 | 1340 | 130 | 10.3 | 1180 | 9.1 |
| | | | Passenger. | 55 | 1340 | 130 | 10.3 | 1180 | 9.1 |
| Illinois Traction. | G.E. . . . | 25 | Freight. . . | 40 | 600 | 50 | 12.0 | . . . . . . | . . . . . . . . |
| Swedish State . . . | West. . . | 25 | Freight. . . | 40 | 460 | 40 | 11.5 | . . . . . . | . . . . . . . . |
| Prussian State. . . | Siemens | 25 | Freight. . . | 40 | 330 | 40 | 8.3 | . . . . . . | . . . . . . . . |
| | Siemens | 25 | Freight. . . | 40 | 1050 | 66 | 16.0 | . . . . . . | . . . . . . . . |
| | A.E.G. . | 25 | Freight. . . | . . . . . . . . . | 1050 | 65 | 16.1 | . . . . . . | . . . . . . . . |
| Pennsylvania | West. . . | 15 | Passenger. | 60 | 920 | 76 | 12.1 | 620 | 8.2 |
| Visalia Electric. . | West. . . | 15 | Freight. . . | 40 | 500 | 47 | 10.6 | . . . . . . | . . . . . . . . |
| Shawinigan. . . . . . | G.E. . . . | 15 | Freight. . . | 40 | 600 | 50 | 12.0 | . . . . . . | . . . . . . . . |
| French Southern. | West. . . | 15 | Freight. . . | 46 | 1200 | 89 | 13.4 | 900 | 10.1 |
| | A.E.G. . | 15 | Freight. . . | 74 | 1600 | 94 | 17.0 | . . . . . . | . . . . . . . . |
| General Electric . | G.E. . . . | 15 | Freight. . . | 40 | 800 | 125 | 6.4 | . . . . . . | . . . . . . . . |
| Swiss Federal. . . . | Siemens | 15 | Freight. . . | 40 | 1350 | 83 | 16.1 | . . . . . . | . . . . . . . . |
| | Oerlikon | 15 | Freight. . . | . . . . . . . . . | 500 | 45 | 11.1 | . . . . . . | . . . . . . . . |
| Baden State | Siemens | 15 | Freight. . . | 75 | 1050 | 71 | 14.8 | 780 | 10.9 |
| (Wiesental) | A.E.G. . | 15 | Freight. . . | 46 | 780 | 71 | 11.0 | . . . . . . | . . . . . . . . |
| Bernese Alps. . . . | A.E.G. . | 15 | Freight. . . | 46 | 1600 | 103 | 15.5 | . . . . . . | . . . . . . . . |
| | Oerlikon | 15 | Freight. . . | 43 | 2000 | 97 | 20.6 | . . . . . . | . . . . . . . . |
| Swedish State . . . | Siemens | 15 | Freight. . . | . . . . . . . . . | 2500 | 110 | 18.2 | . . . . . . | . . . . . . . . |
| | Siemens | 15 | Passenger. | . . . . . . . . . | 1000 | 77 | 13.0 | . . . . . . | . . . . . . . . |
| Prussian State. . . | A.E.G. . | 15 | Freight. . . | . . . . . . . . . | 1000 | 77 | 12.9 | . . . . . . | . . . . . . . . |
| | A.E.G. . | 15 | Freight. . . | . . . . . . . . . | 800 | 64 | 12.5 | . . . . . . | . . . . . . . . |
| Mittenwald. . . . . . | A.E.G. . | 15 | Freight. . . | . . . . . . . . . | 800 | 64 | 12.5 | . . . . . . | . . . . . . . . |

## WEIGHT ANALYSIS OF ELECTRIC LOCOMOTIVE EQUIPMENT.

Direct-current, 600-volt Locomotives.

| Locomotive name. | B. & O. R.R. | B. & O. R.R. | B. & O. R.R. | New York Central. | Michigan Central. | Pennsylvania. | Pennsylvania. |
|---|---|---|---|---|---|---|---|
| Year | 1895 | 1903 | 1910 | 1908 | 1909 | 1910 | 1905 |
| Type | Gearless. | Geared. | Geared. | Gearless. | Geared. | Crank. | Gearless. |
| Motors | 4 | 4 | 4 | 4 | 4 | 2 | 4 |
| H.p. | 1080 | 800 | 1100 | 2200 | 1100 | 2500 | 1280 |
| Weights: | | | | | | | |
| Mechanical | .......... | 115,270 | 130,000 | 157,300 | 136,000 | 197,000 | .......... |
| Motors | .......... | 35,420 | 42,240 | 50,000 | 46,400 | 89,000 | 45,000 |
| Electrical parts | .......... | 9,310 | 11,760 | 22,700 | 17,600 | 28,000 | .......... |
| Total weights | 192,600 | 160,000 | 184,000 | 230,000 | 200,000 | 314,000 | 195,140 |
| On drivers | 192,600 | 160,000 | 184,000 | 141,000 | 200,000 | 200,000 | 195,140 |
| Per cent: | | | | | | | |
| Mechanical | .......... | 72.0 | 70.8 | 68.4 | 68.0 | 62.7 | .......... |
| Motor | .......... | 22.2 | 22.8 | 21.7 | 23.2 | 28.3 | 23.1 |
| Electrical parts | .......... | 5.8 | 6.4 | 9.9 | 8.8 | 9.0 | .......... |
| On drivers | 100.0 | 100.0 | 100.0 | 61.3 | 100.0 | 63.7 | 100.0 |

Pennsylvania 1909 locomotives were modified, and those built in 1910 weigh 157 tons and have 100 tons on the drivers.

## WEIGHT ANALYSIS OF ELECTRIC LOCOMOTIVE EQUIPMENT.

Three-phase, Freight Locomotives.

| Locomotive name. | Giovi or Savona. | Simplon Tunnel. | Simplon Tunnel. | Valtellina. | Valtellina. | Valtellina. | Great Northern. |
|---|---|---|---|---|---|---|---|
| Year | 1908 | 1906 | 1909 | 1902 | 1904 | 1906 | 1909 |
| Type | Crank. | Crank. | Crank. | Crank. | Crank. | Crank. | Geared. |
| Motors | 2 | 2 | 2 | 4 | 2 | 2 | 4 |
| H.p. | 1980 | 1100 | 1700 | 600 | 1200 | 1500 | 1700 |
| Weights: | | | | | | | |
| Mechanical | .......... | 75,000 | 74,000 | .......... | 68 000 | .......... | 111,500 |
| Motors | 54,000 | 50,000 | 55,000 | 44,000 | 55,600 | 54,600 | 59,800 |
| Transformers | 0 | 0 | 13,100 | 0 | 0 | 0 | 20,800 |
| Electrical parts | 6,000 | 15,000 | 10,000 | .......... | 15,000 | .......... | 37,900 |
| Total weights | 134,000 | 140,000 | 152,000 | 104,000 | 138,000 | 138,000 | 230,000 |
| On drivers | 134,000 | 94,000 | 152,000 | 104,000 | 94,000 | 94,000 | 230,000 |
| Per cent: | | | | | | | |
| Mechanical | .......... | 53.5 | 48.7 | .......... | 49.1 | .......... | 48.5 |
| Motor | 40.3 | 35.7 | 36.2 | 42.0 | 40.8 | .......... | 26.0 |
| Transformers | 0 | 0 | 8.6 | 0 | 0 | .......... | 9.0 |
| Electrical parts | 4.5 | 10.8 | 6.5 | .......... | 10.7 | .......... | 16.5 |
| On drivers | 100.0 | 67.0 | 100.0 | 100.0 | 68.0 | 68.0 | 100.0 |

## WEIGHT ANALYSIS OF ELECTRIC LOCOMOTIVE EQUIPMENT.

Single-phase Locomotives.

| Locomotive name. | French Southern | Spokane & I.E. | Bernese Alps. | Grand Trunk. | New Haven freight. | New Haven passenger. |
|---|---|---|---|---|---|---|
| Year | 1909 | 1907 | 1910 | 1907 | 1909 | 1908 |
| Type | Geared | Geared. | Crank. | Geared. | Geared. | Quill. |
| Motors | 2 | 4 | 2 | 3 | 4 | 4 |
| H.p. | 1200 | 680 | 2000 | 720 | 1260 | 960 |
| Weights: | | | | | | |
| Mechanical | 82,960 | 83,379 | 116,560 | 69,580 | 169,872 | 89,000 |
| Heater | ........ | ........ | ........ | ........ | 5,590 | 5,000 |
| Motors | 59,200 | 47,500 | 42,240 | 47,557 | 79,000 | 66,840 |
| Transformers | 18,680 | 6,155 | 24,200 | 5,550 | 14,060 | } 43,160 |
| Elec. parts | 18,020 | 8,126 | 11,000 | 9,313 | 32,349 | |
| Total | 178,860 | 145,160 | 194,000 | 132,000 | 300,871 | 204,000 |
| On drivers | 123,500 | 145,160 | 194,000 | 132,000 | 188,000 | 154,000 |
| Per cent: | | | | | | |
| Mechanical | 46.4 | 57.3 | 60.0 | 52.6 | 58.5 | 46.0 |
| Motor | 33.0 | 32.8 | 21.8 | 36.2 | 26.3 | 32.8 |
| Transformers | 10.3 | 4.3 | 12.5 | 4.2 | 4.6 | } 21.2 |
| Elec. parts | 10.3 | 5.6 | 5.7 | 7.0 | 10.6 | |
| On drivers | 69.0 | 100.0 | 100.0 | 100.0 | 62.5 | 75.5 |

New Haven geared freight locomotive was redesigned in 1910 and the weight reduced to 280,000 pounds.

## SUMMARY ON ANALYSIS OF LOCOMOTIVE WEIGHTS.

| Locomotive. | Direct current. | | Three-phase. | | Single-phase. | | Motor generator. |
|---|---|---|---|---|---|---|---|
| | | ave. | | ave. | | ave. | ave. |
| Weight, mechanical | 50 to 72 | 66 | 48 to 56 | 51 | 46 to 59 | 58 | 43 |
| Weight of motor | 20 to 27 | 24 | 26 to 40 | 30 | 26 to 36 | 27 | 30 |
| Weight of electrical parts | 5 to 10 | 8 | 7 to 10 | 9 | 7 to 11 | 8 | 21 |
| Weight of transformer | 0 | 0 | 0 to 10 | 10 | 8 | 7 | 6 |
| H.p. per ton, about | | 16 | | 18 | | 14 | 8 |

A study of this statistical table shows that data must be used with great care. Note, that the reason why the mechanical weights of direct-current locomotives are high in percentage, is because the electrical weights are low. Three-phase motor weights appear to be high, but this is not true, the fact being that European designers simply use light mechanical frames. As more data are added, the averages will become of more value. The 1-hour h. p. per ton is not a fair basis for comparison. When data on the continuous h. p. per ton are compared the differences decrease.

See table comparing Oerlikon locomotives of Bernese Alps Railway, under "Technical Description of Single-phase Locomotives," page 395.

## MECHANICAL TRANSMISSION OF MOTIVE POWER.

**Motor connections** to locomotive drivers or axles are provided by the use of several schemes, as follows:

1. Gearless motors, with armature *on* axle, connected (a) directly or solid, as in New York Central of 1906; (b) flexibly, by quill over axle and spring connection to drivers by radial arms, as in Baltimore & Ohio of 1896 and New York, New Haven & Hartford passenger locomotives of 1907.

2. Geared motors mounted *between* or *over* axles for gear connection to axle (a) directly, with the center line of motor shaft at or just above the elevation of the center line of the axle, as in motor cars, Great Northern, Grand Trunk, and Michigan Central locomotives; (b) indirectly thru a quill surrounding the axle, which quill is flexibly connected to the arms in the drivers, as in the Boston & Maine geared freight locomotives, the 4 motors of which are directly over the 4 driver axles; (c) indirectly, three gears and side rods, as in Oerlikon locomotives on the Bernese Alps Railway.

3. Crank motors mounted over or between the drivers and crank connected from armature to side rods or to side-rod frames (a) directly, as in Field's locomotive of 1889 (see engraving of same in history of electric locomotives); (b) almost directly, but thru a Scotch yoke, as in the Valtellina and Simplon locomotives, where the 2 motors are connected together and connected to 3 sets of drivers; (c) indirectly thru countershaft, which engages with side rods, as in the Pennsylvania Railroad locomotives.

4. Mounting of motors between drivers and connection thereto by means of wide-faced friction wheels on the armature which engage in friction wheels on the axle. This scheme, used by Daft in his early locomotive, has recently been retried by inventors. The pressure between pulleys is varied by means of compressed air.

**Drivers are coupled** by side rods to prevent slipping of individual drivers, from non-uniform application of power by individual motors, or from varying driver diameters, or from varying tractional friction. When all drivers are coupled, one or more motors may be disabled, yet the remaining motors or motor can distribute the available tractive effort to all of the drivers.

**Gears versus cranks,** with or without crank shafts, for the mechanical connection between armature and drivers, are frequently debated. The superiority of either has not yet been generally established.

With slow-speed train haulage, gears at each end of an armature shaft are fairly satisfactory. For high-speed train haulage, large locomotive motor gears of the ordinary spur type with the best well-machined steel,

wide faces, and with high-pressure oil lubrication are not able to withstand the wear. The repeated shock, as the teeth engage, destroys them quickly after the axle and motor bearings are worn A gradual engagement of teeth, which is possible with special gearing, is being tried out in high-speed service by Oerlikon locomotives on European railroads.

**Relation of speed to driver diameter** is now considered.

Observe that high-speed, geared motor armatures, 500 to 1000 r.p.m., are advantageous because they decrease the weight and the diameter of the motor. Speeds of 200 to 500 r.p.m. are required for gearless motors. See Armature Speed of Motors, under Motor Design, Chapter V.

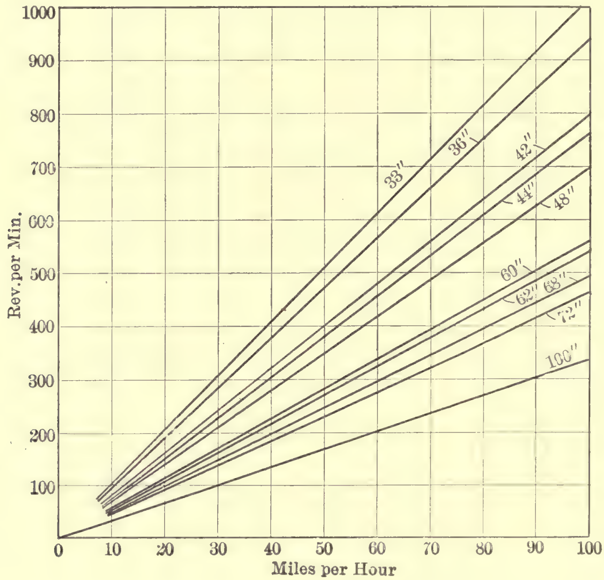


Fig. 83.—Diagram Showing Relation of Revolutions per Minute and Miles per Hour to Driver Diameter.

Driver diameters are made as large as possible to increase the area of the rail contact to decrease the intensity of pressure, stress, and wear, and the maintenance and renewal cost, of both the rail and the drivers. Lower surface speed of journals is also gained. With geared and crank types of locomotives, some motor and driver restrictions are removed.

Drivers less than 44 inches in diameter are not practical for large gearless locomotives. New York Central locomotives with 44-inch drivers, at 500 r. p. m., run at 66 m. p. h. It would not be practical to build a larger motor of this type for slow-speed freight service; for, as

shown by the accompanying diagram, if 44-inch drivers are used, the speed of the armature would be low. For example, with 250 r. p. m. or 33 m. p. h., the diameter of the motor would be too large for the drivers.

New Haven gearless passenger locomotives, with 62-inch drivers, at 380 r. p. m., run at 70 m. p. h., and at 325 r. p. m., run at 60 m. p. h.

Driver diameters are thus involved in the design of the mechanical connections between the armature and the axle.

DRIVER DIAMETERS USED IN ELECTRIC LOCOMOTIVES.

| Name of railroad. | Kind of service. | Power h.p. | Trailing tons. | Balance speed, m. p. h. | Grade. p.c. | Driver diameter. |
|---|---|---|---|---|---|---|
| New York Central...... | Passenger.... | 2200 | 435 | 60 | 0 | 44″ |
| Baltimore & Ohio ..... | Passenger.... | 1080 | 900 | 16 | 1.5 | 62 |
| Baltimore & Ohio...... | Freight...... | 800 | 1020 | 9 | 1.5 | 42 |
| Baltimore & Ohio...... | Freight...... | 1100 | 850 | 26 | 0 | 50 |
| | | | | 18.5 | 1.5 | 50 |
| Pennsylvania.......... | Passenger.... | 2500 | 550 | 60 | 0 | 72 |
| New Haven 41........ | Passenger.... | 960 | 250 | 70 | 0 | 63 |
| 69........ | Freight...... | 1396 | 1500 | 35 | 0 | ............ |
| 70........ | Freight...... | 1350 | 1500 | 35 | 0 | 57 |
| 71........ | Freight...... | 1260 | 1500 | 35 | 0 | 63 |
| 71........ | Passenger.... | 1260 | 800 | 45 | 0 | 63 |
| 0200...... | Switch...... | 600 | 450 | 26 | 0 | 63 |
| Bernese Alps......... | Passenger.... | 2000 | 280 | 25 | 2.7 | 53 |
| Giovi................ | Freight...... | 1980 | 209 | 28 | 2.7 | 42 |
| Grand Trunk.......... | Passenger.... | 720 | 400 | 25 | 0 | 62 |
| | Freight...... | 720 | 1000 | 10 | 2.0 | 62 |
| Michigan Central...... | General...... | 1100 | 900 | 10 | 2.0 | 48 |
| Great Northern........ | General...... | 1900 | 500 | 15 | 1.7 | 60 |
| Paris-Orleans ......... | Passenger.... | 1200 | 300 | 30 | 0 | 49 |
| implon ............. | General...... | 1700 | 440 | 43 | 0.7 | 49 |

**Gearless motors mounted on locomotive axles** have, as characteristic features of design, simplicity of mechanical and also electrical construction, high efficiency, very heavy dead weight, low maintenance, small diameter of drivers, low center of gravity, and high track maintenance. The design is not suitable for freight service. Gearless operation, while desirable, requires high train speed. Peripheral speeds of armatures are less than the train speed, in feet per minute.

**Gearless motors, mounted on quills** surrounding the driver axles have a higher weight, and cost. Suspension of the stator on the locomotive frames, and spring-mounting of the armature, greatly reduce the cost of motor and track maintenance.

**Geared motors** allow either a partial or a complete spring-mounting of the motor, and with ordinary drivers, a much higher motor speed, decreased weight, and lower cost.

Great Northern locomotives, for 15 m. p. h., with 60-inch drivers have a driver speed of 84 r. p. m. The gear ratio used is 4.26, making the speed of the motor 358 r. p. m. at full load. Gearing is placed at each end of the armature shaft. Armatures are 36 inches in diameter.

Motor cars with 36-inch wheels, running at 45 m. p. h. maximum, have a driver speed of 420 r. p. m. Gear ratios of 3 allow a small-diameter armature to run at 1260 r. p. m.

Geared freight locomotives with 62-inch drivers running at 35 m. p. h., or 186 r. p. m., require a gear ratio of 2.3 to 3.0 in order to get a light weight, geared motor (New Haven freight); but if the maximum speed is to be 25 m. p. h., the gear ratio must be from 4 to 5 in common cases (Grand Trunk, Spokane & Inland, Michigan Central). Quill and spring connection requires large drivers.

Geared motors with one end mounted directly on the axle are not suitable for high-speed work, because, with non-spring-borne motors the power exerted by concussion, $1/2Mv^2$, destroys the track.

**Crank and side-rod constructions** are not a recent development in locomotive design.

Stephen D. Field's locomotive, which was tried on the Thirty-fourth Street branch of the New York Elevated Railroad in 1889, had two coupled axles on the rear or driving truck, as in an Atlantic type steam locomotive. The armature of the motor had an extended crank which was connected to the middle of the side rod. The effort exerted was absolutely uniform. MARTIN AND WETZLER, "The Electric Motor," 1889, p. p. 190 and 204; Electrical Engineer, Dec. 9, 1891.

North American locomotive, designed by Sprague, Hutchinson, and Duncan, in 1893, had the motors between the drivers, and side rods connecting the drivers, but the armatures were not crank-connected.

Valtellina locomotives of 1902 appear to have been next to follow the crank and side-rod construction, including the use of Scotch yoke. See description of Valtellina, Simplon Tunnel, and Giovi locomotives, in Chapter IX.

The jackshaft between the crank rod from the armature shaft and the side rod became a necessity to allow for inequalities in the elevation of the track.

Crank and side-rod construction, or gears, with cranks and siderods, with or without jackshafts, has these advantages:

1. Tractive effort is increased by coupling the driving axles. Consult: Dodd, A. I. E. E., June, 1905; Sperry, A. I. E. E., June, 1910. In case one motor is out of service the adhesion is furnished by each driver.

2. Center of gravity is high and this is an advantage in relieving the strain on the head of the rail when the locomotive rocks or cants outward in rounding a curve.

3. Spring supports are practical for the armatures and fields of heavy motors. The dead weight per axle and track maintenance are reduced.

4. Limitations of space, particularly between the drivers, are removed, and motor design may be perfected.

5. Distribution of weight is improved, in many cases.

6. Number of motors may be decreased, from three or four to two or three, which affects cost, weight, and simplicity.

7. Motors are located out of the dust and dirt, and it is not necessary to enclose them. Motors may then be made independent of the truck, and armatures can readily be removed without dismantling the motor or taking off a driving wheel. Insulation space is not limited when large motors and large diameters are used; and the insulation is not subjected to water from the road-bed. Higher voltages may thus be used on fields.

8. Accessibility is obtained for quick inspection and repair work on motors, to reduce maintenance cost.

9. Bearings of armatures may have proper proportions.

10. Air gaps, when necessarily small, become practical.

11. Efficiency, power factor, and torque are improved.

12. Design of jackshaft (crankshaft) is such that the motor may be located in about any advantageous position on the frames.

13. Side rods, standardized for steam locomotives, may be used.

**Disadvantages of crank design** with or without countershaft:

1. Side rods, countershafts, and cranks are heavy, cumbersome; and increase the friction, and are objectionable mechanically, compared with geared connections. Simplicity is sacrificed.

2. Strains in countershaft, crank, and shaft are large.

3. Bearings of motor and countershaft must be large, and motor supporting frames must be wide, to keep armature bearings out from under collectors and commutators. Losses occur in extra bearings, and pounding results from lost motion.

4. Designs of railway motors, smaller than 400-h.p., work out simpler and better, *i. e.*, the side rod and countershaft are not necessary.

5. Heavy slow-speed motors increase the weight and cost.

**Reference:** E. R. J., Oct. 6, 1910; Elec. Journal, Sept., 1910.

CRANK AND SIDE-ROD ELECTRIC LOCOMOTIVES.

| Name of railroad. | No. of loco. | Year built. | Name of Mfgr. | Rated h.p. | No. of cycles. | Voltage used. | No. of motors. | Wt. tons. |
|---|---|---|---|---|---|---|---|---|
| New York Elevated. | 1 | 1889 | Field... | 22 | 0 | 600 | 1 | 13 |
| Pennsylvania...... | 33 | 1910 | West... | 2500 | 0 | 660 | 2 | 157. |
| Valtellina......... | 4 | 1906 | Ganz... | 1500 | 15 | 3,000 | 2 | 75 |
| Giovi and Savona.. | 40 | 1909 | West... | 1980 | 15 | 3,000 | 2 | 67 |
| Simplon Tunnel.... | 2 | 1906 | Brown.. | 1100 | 15 | 3,000 | 2 | 70 |
| Simplon Tunnel.... | 2 | 1909 | Brown . | 1700 | 15 | 3,000 | 2 | 76 |
| Oerlikon.......... | 1 | 1909 | Oer..... | 400 | 15 | 15,000 | 2 | 46 |
| Bernese-Alps ...... | 1 | 1910 | Oer..... | 2000 | 15 | 15,000 | 2 | 97 |
| Bernese-Alps ...... | 2 | 1910 | A.E.G.. | 1600 | 15 | 15,000 | 2 | 103 |
| French Southern... | 6 | 1910 | A.E.G.. | 1600 | 15 | 12,000 | 2 | 94 |
| French Southern... | 1 | 1910 | West... | 1600 | 15 | 12,000 | 2 | 89 |
| Baden State ....... | 10 | 1909 | Siem ... | 780 | 15 | 10,000 | 2 | 71 |
| (Weisental Ry.).. | 2 | 1909 | Siem ... | 1050 | 15 | 10,000 | 2 | 98 |
| General Electric ... | 1 | 1909 | G.E.... | 800 | 15 | 11,000 | 2 | 125 |
| New Haven (freight) | 1 | 1910 | West... | 1350 | 25 | 11,000 | 2 | 135 |
| St. Polten-Mariazell | 17 | 1910 | Siemens | 500 | 25 | 6,000 | 2 | 50 |
| Swedish State..... | 13 | 1911 | Siemens | 2000 | 15 | 15,000 | 2 | 110 |
| | 2 | 1911 | Siemens | 1000 | 15 | 15,000 | 2 | 77 |
| Prussian State..... | 10 | 1911 | see p. 355. | ...... | 15 | 10,000 | 2 | ..... |
| Mittenwald ........ | 6 | 1911 | A.E.G. | 800 | 15 | 10,000 | 1 | 64 |

### COST OF ELECTRIC LOCOMOTIVES.

| Name of railroad. | Electric system. | Kind of service. | Year built. | Wt. tons. | Total h.p. | Estimated cost. | Per h.p. | Per lb. |
|---|---|---|---|---|---|---|---|---|
| Baltimore & Ohio..... | D. C.... | Freight... | 1903 | 80 | 800 | $19,000 | $23.75 | 11.9¢ |
| New York Central.... | D. C ... | Passenger. | 1905 | 95 | 2200 | 27,000 | 12.27 | 14.2 |
| New York Central.... | D. C.... | Passenger. | 1908 | 115 | 2200 | 33,000 | 15.00 | 14.3 |
| Pennsylvania R. R.... | D. C ... | Passenger. | 1910 | 157 | 2500 | 65,000 | 26.00 | 20.7 |
| Illinois Traction...... | D. C.... | Freight... | 1908 | 40 | 360 | 14,000 | 38.90 | 17.5 |
| Boston & Albany .... | D. C.... | At Boston | Estimate | ....... | ....... | 34,650 | ........ | ...... |
| Milan-Varese........ | D C.... | Freight... | 1902 | 39 | 640 | 12,000 | 18.75 | 15.4 |
| Galt, Preston & H ... | D. C.... | Freight... | 1911 | 50 | 400 | 16,000 | 40.00 | 16.0 |
| Great Northern....... | 3–P .... | General... | 1909 | 115 | 1700 | 40,000 | 23.53 | 17.4 |
| Simplon Tunnel...... | 3–P .... | General... | 1909 | 68 | 1700 | 27,500 | 16.20 | 20.2 |
| New Haven ......... | 1–P..... | Passenger. | 1907 | 102 | 1000 | 45,000 | 45.00 | 22.0 |
| New Haven ......... | 1–P .... | Freight... | 1909 | 140 | 1350 | 60,000 | 44.44 | 21.5 |
| New Haven ......... | 1–P.... | At Boston | Estimate | ....... | ...... | 42,500 | ........ | ...... |
| Boston & Maine ..... | I–P.... | General... | 1911 | 130 | 1380 | 50,000 | 36.23 | 19.2 |
| Grand Trunk........ | 1-P .... | General... | 1908 | 66 | 720 | 26,500 | 36.80 | 20.1 |
| Ordinary............ | 1-P .... | Switcher.. | 1911 | 80 | 600 | 20,000 | 33.33 | 12 5 |
| Prussian State........ | 1–P .... | General... | Estimate | ....... | ....... | ......... | ........ | 18.3 |
| St. Gothart.......... | 1–P .... | General.. | Estimate | ...... | ....... | 28,000 | ........ | ...... |

Cost of steam locomotives is about $15 per h. p., and the cost per pound varies from 6.7 to 8.0 cents.

Electric locomotive motor rating is on the 1-hour basis; with forced draft the continuous rating is about 80 per cent. of the 1-hour rating. When reduced to cost per continuous h. p., the cost per h. p. and per pound is not radically different with different modern designs.

The cost varies with the state of the art, and with the number of locomotives of a type developed which have been sold. The cost of a small switching locomotive, per h. p. and per pound, is not much less than for a heavy locomotive in terminal service or in trunk-line haulage.

Reduction in cost is of vital importance and can be accomplished by the use of cheaper materials, steel plate and rolled shapes in place of cast steel, less labor in building up steel parts, and standardization.

## LITERATURE.

### References on Characteristics of Electric Locomotives.

(See references at the end of Chapter III on Physical and Financial Advantages of Electric Traction.)

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Valatin: Heavy Electric Railroading, E. W., Nov., 1905, p. 860.

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Lamme: Alternating Current for Heavy Railway Service, S. R. J., Jan. 6, 1906.

See technical descriptions of freight locomotives, which follow.

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**References on Side-rod Construction for Electric Locomotives.**

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For Valtellina, Simplon Tunnel, Giovi, New Haven, Pennsylvania R.R., Oerlikon, General Electric, etc., see technical descriptions which follow.

Pittsburg Street Railway, Side-rod Trucks, S. R. J., Dec. 14, 1907; Oct. 15, 1910.

Motor Mounting on Locomotive: E. R. J., Apr., 1910, p. 667, and Oct. 15, 1910, p. 835.

Motor Suspension: See "Development of Motor Design," Chapter V.

# CHAPTER VIII.

## TECHNICAL DESCRIPTION OF DIRECT-CURRENT LOCOMOTIVES.

### Outline.

| Direct-current Locomotives: | No. | Wheel order. | Year. | H. P. | Tons. | Page. |
|---|---|---|---|---|---|---|
| Baltimore & Ohio R.R. . . . . . . . . . . | 5 | 0–4–4–0 | 1895 | 1080 | 96 | 303 |
| | 5 | 0–4–4–0 | 1903 | 800 | 80 | 304 |
| | 2 | 0–4–4–0 | 1910 | 1100 | 92 | 306 |
| Buffalo & Lockport R.R. . . . . . . . . . | 2 | 0–4–4–0 | 1898 | 640 | 38 | 307 |
| Bush Terminal R.R. . . . . . . . . . . . . . | 4 | 0–4–4–0 | 1904 | 360 | 40 | 308 |
| Philadelphia & Reading Ry. . . . . . | 1 | 0–4–4–0 | 1904 | 200 | 20 | 309 |
| Hoboken Shore R.R. . . . . . . . . . . . . . | 4 | 0–4–4–0 | 1898 | 400 | 64 | 309 |
| New York Central & H. R. R. R. . . | 35 | 2–8–2 | 1906 | 2200 | 95 | 310 |
| | 12 | 4–8–4 | 1908 | 2200 | 115 | 310 |
| Michigan Central R. R. . . . . . . . . . . . | 6 | 0–4–4–0 | 1910 | 1100 | 100 | 318 |
| Pennsylvania R.R.: | | | | | | |
| Experimental on Long Island . . | 2 | 0–4–4–0 | 1907 | 640 | 97 | 321 |
| New York Terminal Division. . . | 33 | 4–4–4–4 | 1910 | 2500 | 157 | 322 |
| Galt, Preston & Hespler Ry. . . . . . | 2 | 0–4–4–0 | 1910 | 400 | 50 | 329 |
| Illinois Traction Company. . . . . . . | 20 | 0–4–4–0 | 1907 | 960 | 60 | 330 |
| North-Eastern Ry., England. . . . . . | 6 | 0–4–4–0 | 1904 | 640 | 55 | 331 |
| Metropolitan Ry., England. . . . . . | 10 | 0–4–4–0 | 1905 | 800 | 52 | 332 |
| Paris-Orleans Ry., France . . . . . . . . | 8 | 0–4–4–0 | 1900 | 1000 | 55 | 332 |
| | 3 | 0–4–4–0 | 1904 | 1000 | 61 | 332 |
| Rombacher-Huette Ry., France . . | 3 | 0–4–4–0 | 1906 | 640 | 62 | 334 |

**Literature on Other Direct-current Locomotives, 335.**

**References to Detailed Drawings of Direct-current Locomotives, 336.**

# CHAPTER VIII.

## DESCRIPTION OF DIRECT-CURRENT LOCOMOTIVES.

### IN GENERAL.

**The number of electric locomotives which use direct-current** at about 600 volts, which the author has obtained by correspondence and from printed lists, in America is 357, and in Europe is 112, of which 52 are on the City and South London Railway.

The number of electric locomotives on railroads which use three-phase current in America is 4, and in Europe 56.

The number of electric locomotives which use single-phase current in America is 90, and in Europe is about 134.

The technical descriptions which follow cover only the most important and typical installations. The nature of the facts is of importance.

### BALTIMORE & OHIO PASSENGER, 1895.

**Baltimore & Ohio Railroad,** in 1895, placed in service 5 gearless locomotives, between the Baltimore station yards and Waverly, 3.7 miles, including the Baltimore Belt line tunnel, 7200 feet long. About 7 miles of track are electrified. Grades average 1.00 per cent. but the ruling grade is 1.5 per cent. Curves included seven, from 5 to 11 degrees. The locomotives are still doing good work.

The service for which the locomotives were designed was for hauling freight and passenger trains over the above route, grades, and curves. Three stops are made by the passenger trains in the 3.7-mile run. About 21 passenger trains are now hauled up the grades per day, but trains run down without help from the locomotives. The speed up-grades is about 16 m. p. h. The average passenger train, including steam and electric locomotive, weighs 990 tons.

**Two trucks** are used, each with a wheel base of 6 feet 10 inches. The total wheel base is 23 feet 2 inches. The weight on four pairs of 60-inch drivers is 96 tons. The locomotive length is 35 feet.

**Motor equipment** consists of four General Electric AXB-70, 600-volt direct-current motors, rated 1440 h. p. per locomotive. In order to reduce the locomotive speed, the motors were designed with 6 poles and each pair of motors was connected permanently in series. The rating with motors in series is 1080. (G. E. bulletin 4390 gives the rated h. p. as 720.) Gearless armatures are used, spring-suspended on a quill surrounding the axle. The field is spring-supported on the frame, and centered around the armature quill by means of bearings. The torque of the armature is transmitted from radial arms on the armature shaft to the spokes in the drivers, thru rubber compression blocks located at the ends

of the radial arms; the arrangement is desirable since it compensates for variation in track alignment and provides a flexible connection. See Figures 47, 48.

**Tests** show that the 96-ton locomotive starts an 1870-ton train from rest against such a grade as to require a tractive force of 63,000 pounds, or 32 per cent. of the locomotive weight. The drawbars are stretched, and the train accelerated to 12 m. p. hr. without slipping the drivers.

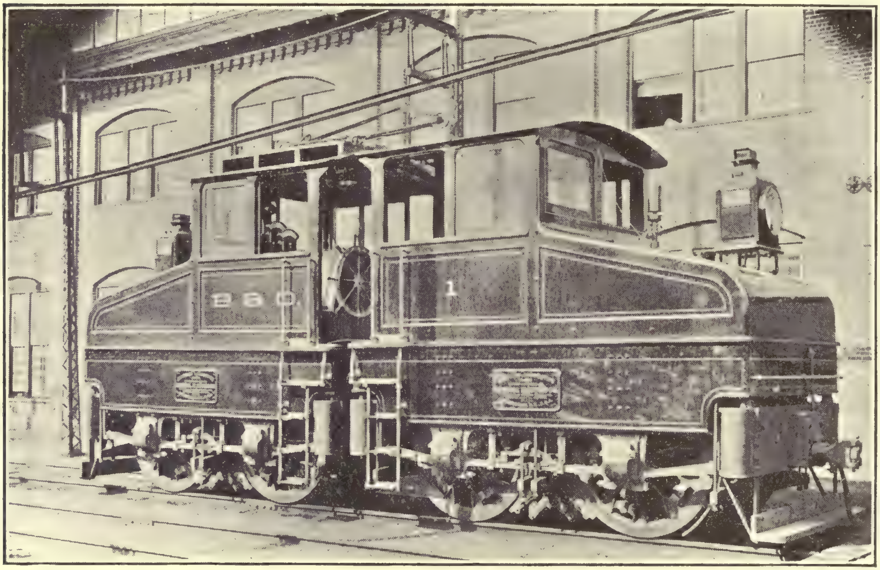

FIG. 84.—BALTIMORE & OHIO RAILROAD PASSENGER LOCOMOTIVE USED SINCE 1895.

The dynamometer car records of drawbar pull show that the amplitude of vibrations is, under similar conditions, considerably less than that with the changing crank angle of steam locomotives.

**In design,** these 5 locomotives, built in 1895, were too fast for freight service. It was found that the locomotive wheel base was short, and the weight was concentrated. Operating results, for over 16 years, have been excellent. These locomotives were the first heavy railroad locomotives in America. Their success was remarkable and was of great importance historically.

### BALTIMORE & OHIO FREIGHT, 1903.

**Baltimore & Ohio Railroad,** in 1903, purchased 5 additional locomotives for freight service at Baltimore. Each weighs 80 tons and is rated 800 h. p. Two locomotives are used per train.

The service for which the 1903 locomotives were designed was to haul

2300-ton freight trains at a speed of 10 m. p. h.; 1800-ton freight trains at 12 m. p. h.; and 500-ton passenger trains at 35 m. p. h. on the level.

**Specifications** for the 1903 locomotives required that two units should work together normally, and be capable of handling a 1500-ton train, including the steam locomotive, but excluding the electric locomotive, on a maximum grade of 1.5 per cent. at 10 miles per hour, and at higher speeds on lighter grades. The locomotive was to have sufficient capacity to maintain this service hourly, running loaded on the up-grade and returning light.

**Weight** of locomotive unit is 160,000 pounds, all on drivers. The adhesion at 25 per cent. is 40,000 pounds or 80,000 for the pair. The


FIG. 85.—BALTIMORE & OHIO RAILROAD FREIGHT LOCOMOTIVES OF 1903.

grade, friction, and acceleration require this maximum drawbar pull, and weight for tractional effort. The weight, 80 tons per unit, is distributed over 4 sets of 42-inch drivers. The total and the rigid wheel base of each unit is 14 feet 6 3/4 inches, and the wheel base of two units is 44 feet 2 3/4 inches.

**Tractive effort** at working load and at 8.5 m. p. h. for two units is 70,000 pounds. These locomotives haul, on an average, 28 freight trains per day with an average weight of 1980 tons, on the above grades.

**Motor equipment** consists of 4 motors per 80-ton locomotive unit, type G. E.-65 B, rated 200 h. p. at 625 volts. Gearing ratio is 81 to 19. Sprague-G. E. type M-C. controllers are used to handle two units.

**Operation** of these freight locomotives has been successful.

## BALTIMORE & OHIO, 1910.

**Baltimore & Ohio Railroad,** in March, 1910, placed in service two additional geared freight locomotives.

The service required that 850-ton freight and occasionally 500-ton passenger trains should be hauled on the level, at 26 and 30 m. p. h., respectively, and up the 1 1/2 per cent. grade at 15.5 and 20 m. p. h.

Specifications required that with two units the drawbar effort up to 15 m. p. h. was to exceed 90,000 pounds.

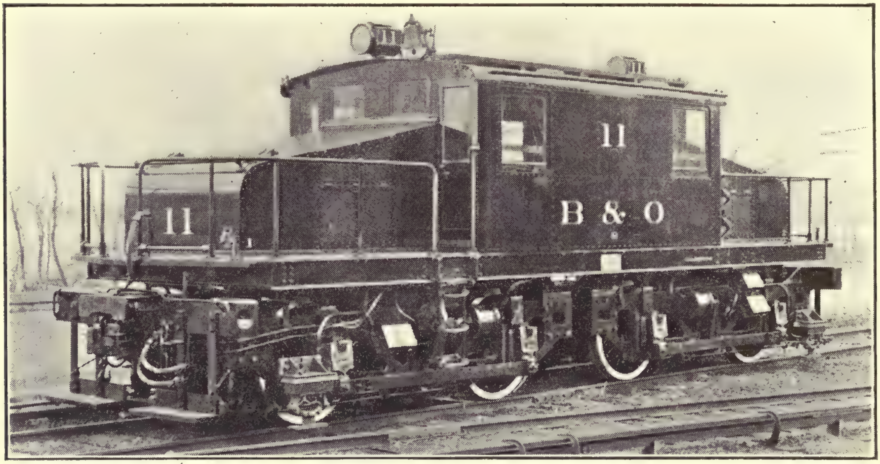


Fig. 86.—Baltimore & Ohio. Freight Unit of 1910.

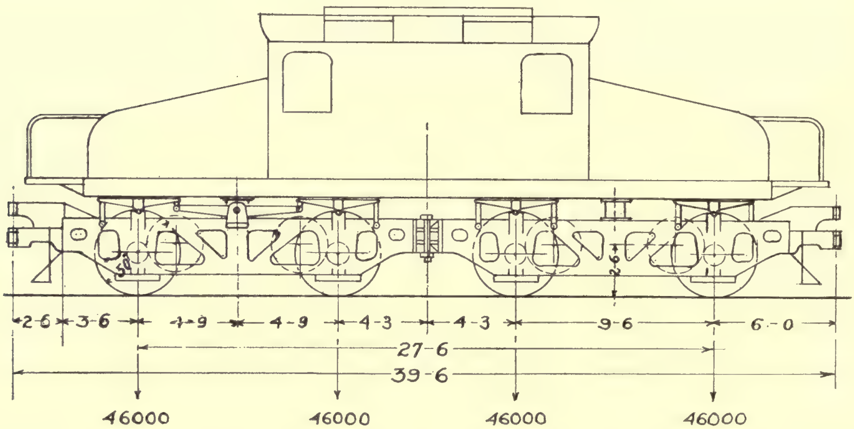


Fig. 87.—Baltimore & Ohio Railroad Locomotive, 1910.
Two used at Baltimore. 92-ton, 1100-h. p., direct-current, 600-volt. Four motors. Gear ratio 3.25. Forced ventilation. Freight service.

Motors are four G. E.-209, 275-h.p., forced ventilated, geared type similar to those on the Michigan Central locomotives, to be described. The gear ratio is 3.25 and gears are mounted on each wheel hub. Four motors weigh 21 tons. See motor drawings, Figure 43.

Trucks are two, 4-wheeled, permanently linked together with a heavy hinge, which allows the two trucks to support and guide one another. Stresses, in pushing and hauling, are transmitted thru the truck framing. The trucks are similar to those of the 1909 Michigan Central articulated locomotive, described later in great detail. Rigid wheel bases are 9 feet 6 inches; total wheel base is 27 feet 6 inches; drivers are 50 inches. Journals are 7 1/2x14. The two platform center pins have a slight longitudinal sliding motion.

The operator works in the center of the cab, where he has the best command of all apparatus, a fair view of the train behind and of a switchman at the coupler.

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The service of the 12 locomotives per annum amounts to about 200,000 locomotive miles, the hauling of 16,000,000 tons, or of 60,000,000 ton-miles, including electric locomotives, and a total train-miles of 66,000. The locomotives work only on the up-grade.

**References on Baltimore & Ohio Locomotives.**

1895: 96-ton, S. R. J., July, 1895; pp. 461 and 827; March 14, 1903; Elec. Engineer, Nov. 5, 1895, March 4, 1896. Tests, E. W., March 7, 1896. Motors, S. R. J., March 14, 1903; June 25, 1904.

1903: 160-ton, S. R. J., Aug. 22, 1903; June 25, 1904; Elec. Review, April 26, 1896; S. R. J., Feb. 24, 1906; G. E. Bulletin No. 4390. A. I. E. E., Nov. 20, 1909, Davis, in discussion of Dr. Hutchinson's paper.

1910: 92-ton, E. R. J., Nov. 26, 1910; G. E. Review, Dec., 1910, p. 534.

See Michigan Central locomotives, which are similar.

## BUFFALO & LOCKPORT.

**Buffalo & Lockport Railway Company,** a subsidiary of the International Traction Company, has operated two electric locomotives since 1898 in freight service. The road runs from Lockport to North Tonawanda, N. Y., 14 miles, and was leased from the Erie Railroad for 999 years. Electric passenger service is furnished by motor-car trains.

Locomotives are of the two swivel-truck-type. They were designed to haul 10 cars, or a 450-ton trailing load at 14 m. p. h. Locomotives have frames of 8-inch channels, 13-foot truck centers, 6-foot truck-wheel base, 36-inch drivers, a length of 32 feet, and a weight of 38 tons. Motors are four G. E.-55, rated 160-h. p. each. A 3.28 gear ratio is used. Each pair of motors runs in series on a 600-volt direct-current circuit.

**Reference.** S. R. J., Sept., 1898, p. 535. See motors, Figure 30.

## BUSH TERMINAL RAILROAD.

**Bush Terminal Railroad** of South Brooklyn since 1904 has employed a 50-ton locomotive for switching at its extensive docks and warehouses.

FIG. 88.—BUFFALO AND LOCKPORT FREIGHT UNIT. TWO USED SINCE 1898.

FIG. 89.—BUSH TERMINAL RAILROAD FREIGHT LOCOMOTIVE.

Two swivel trucks are used, with equalized side-bar frames similar to those in general use for coal-tender trucks of steam locomotives. The bolsters are carried rigidly on the side frames, the weight being transmitted thru one semi-elliptic spring on each side. Axles are 6-inch, drivers are 33-inch. Rigid wheel bases are 6 feet 6 inches; total wheel base 22 feet; and total length 30 feet.

Motors consist of four 90-h. p., 2-turn, direct-current, 500-volt units, with a 2.47 gear ratio. A pantograph trolley is used to prevent frequent reversals, in switching service.

In 1907, and in 1911, locomotives of the same type were purchased. These are 40-ton machines with the same size of motor. The gear ratio is 3.53 and the drivers 36 inches. Weight of electrical equipment is 14 tons.

Performance characteristics for the 1904 machine show a tractive effort of 20,000 pounds at 9 m. p. h., with 800 amperes at 500 volts, and 8000 pounds at 12 m. p. h. with 450 amperes; and for the 1907 locomotive, a tractive effort of 16,800 pounds at 8 m. p. h., with 625 amperes at 500 volts, and 12,000 pounds at 9 m. p. h., with 475 amperes.

**Reference.** G. E. bulletins 4390 and 4537; G. E. Review, Nov., 1907.

### PHILADELPHIA & READING.

**Philadelphia & Reading Railway** in 1904 placed an electric locomotive in service on its 7-mile branch road from Cape May Point to Sewell Point, New Jersey, for freight and passenger service. The locomotive was built by the Baldwin Locomotive Works.

Weight of locomotive is 20 tons, all on drivers. Frames are of steel channels, heavily braced. The length over end sills is 23 feet. Two swivel trucks are used, each with a 6-foot base. Truck centers are 12 feet. Drivers are 30-inch.

Motors are 4, Westinghouse, 38-B., 50-h.p., geared 68 to 14. Control is Westinghouse, type K-14. Automatic and straight air are used.

**Reference.** S. R. J., Description and photograph, Nov. 5, 1904, p. 841.

### HOBOKEN SHORE R. R.

**Hoboken Shore Railroad** since 1898 has operated an extensive freight terminal at Hoboken, N. J. There are 10 miles of electrically operated single track. The freight handled comes from the Lackawanna, Erie, West Shore, Pennsylvania, and Lehigh Valley roads. It is collected and distributed to industrial sidings, freight warehouses, and to extensive steamship docks on the Hudson River.

Four geared, swivel-truck, direct-current, electric locomotives are

used. The service consists of switching and shunting 100 to 150 cars per 10-hour day. Mileage per locomotive per day averages 130.

The G. E. 1898 locomotive has two McGuire trucks, 40-inch drivers 10,000-pound drawbar pull at 8 m. p. h., weighs 28 tons, and is rated 560 h. p. A 4-wheeled G. E. locomotive, built in 1900, is no longer used.

The Westinghouse 1906 locomotive has Baldwin trucks, 33-inch drivers, 15,000-pound drawbar pull at 6 m. p. h., weighs 64 tons, and is

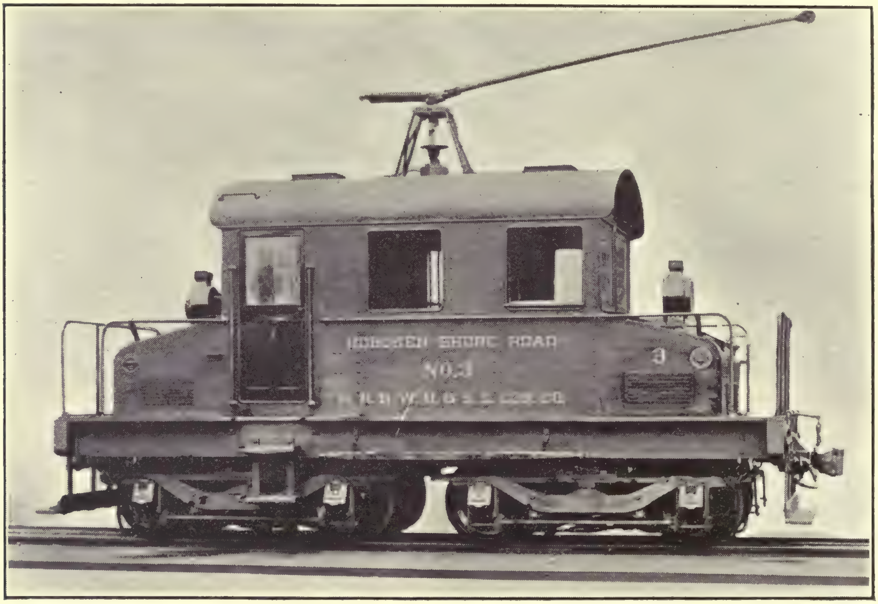


Fig. 90.—Hoboken Shore Freight Switching Locomotive.
64-ton, 400-h. p., Westinghouse unit used since 1906.

rated 400 h. p. This is a modern unit. It hauls 800-ton trains up 1 1/2 per cent. grades and around sharp curves.

The G. E. 1911 locomotive has American trucks, 42-inch drivers, and weighs 80 tons.

C. de Bevoise, Manager, states that the repairs and renewals on these locomotives during the last three years have been $55 for a new pair of wheels, and $12 for brushes and commutator turning.

**Reference.** E. W., Jan. 8, 1898; Elec. Review, July 2, 1910.

## NEW YORK CENTRAL.

**New York Central & Hudson River Railroad,** since Dec., 1906, has operated 35 electric locomotives, and, in 1908, added 12 locomotives, making the total number 47. All New York Central trains in and out

of the Grand Central Station have been electrically operated since July 1, 1907.

**Specifications of contract** with General Electric Co., required that:

Cars weighing 450 tons be hauled from Grand Central Station to Croton, 34 miles, in 60 minutes; there to have a 20-minute layover, and then return to Grand Central Station with a similar train, making one stop in each straight trip.

Cars weighing 335 tons (Empire State Express) be hauled over the same distance, 34 miles, in 44 minutes, then to have a 60-minute layover, then to return to Grand Central Station with a similar train, then to have a layover of 60 minutes, and to keep this service up continually.

Cars weighing 300 tons be hauled over the same distance, 34 miles, in 60 minutes, making 3 stops, with a layover at the end of each 34 miles, of 60 minutes; and this cycle to be operated continually.

Two locomotives were to haul a total train weight, including locomotives of 875 tons at a maximum speed of 65 miles per hour. Temperatures, measured by thermometers, to be within A. I. E. E. limits. Acceleration rate to be to 40 m. p. h. in 121 seconds, or 0.33 m. p. h. p. s.; braking to be at 1.5 m. p. h. p. s.

**The service** for which the locomotives were designed was for passenger work at the New York terminal. Trains are now hauled north from the Grand Central Station, in terminal and switching service, on the

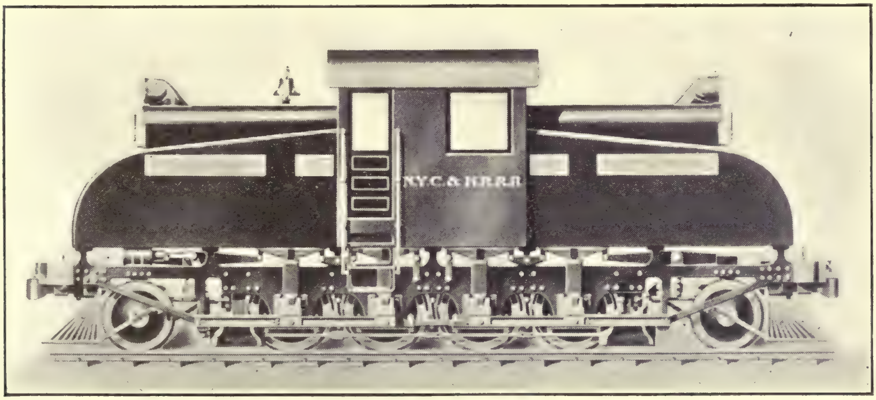


FIG. 91.—NEW YORK CENTRAL LOCOMOTIVE.
Drawing of proposed locomotive, 1905.

Harlem Branch, to the Mott Haven storage yards, a distance of 5.1 miles; in express service, to High Bridge on the Hudson Division, a distance of 7.1 miles; and in express service on the Harlem Division, to North White Plains, a distance of 24 miles. The run on the last division is for light trains. The service is not trunk-line work, since the distances are short. The locomotives are able to work in excess of their rating, since they have ample time to cool off. At all times, including the heaviest service for the Hudson-Fulton celebration, October, 1909,

and on July 4, 1910, there were more electric locomotives than were needed for the work.

**The design** of the locomotives is due to Mr. Batchelder of the General Electric Company, who created a gearless machine.

"The previously accepted principle of fixity of relation between field and armature was abandoned, the latter being mounted directly on the axle and the fields being carried upon and as an integral part of the locomotive frame, supported by its springs and hence moving freely, irrespective of the armature. Gears and axle bearings are dispensed with, and the acme of simplicity of motor construction reached. The armature of course could be spring borne." Sprague, to A. I. E. E., Jan. 25, 1907.

The gearless motor design is somewhat similar to that used in 1897 for the Paris-Lyon-Mediterranean electric locomotive. See detailed drawings in E. W., Feb. 4, 1899.

The wheel arrangement, the base, and the locomotive weight have been changed in design, as noted in the next table.

MODIFICATIONS IN NEW YORK CENTRAL ELECTRIC LOCOMOTIVE DESIGN.

| Tons total. | Tons on drivers. | Wheel base. | Wheel class. | Year. | Reference or notes on modifications. |
|---|---|---|---|---|---|
| 85 | 67 | 27 | 2–6–2 | 1904 | Wilgus, S.R.J., Oct. 8, 1904, p. 584. |
| 85 | 65 | 27 | 2–6–2 | 1904 | Sprague, S.R.J., Oct. 8, 1904. |
| 95 | 69 | 27 | 2–6–2 | 1904 | S.R.J., Nov. 19, 1904. |
| 95 | 68 | 27 | 2–6–2 | 1906 | G.E. bulletin 4390. |
| 100 | 70 | 27 | 2–6–2 | 1907 | S.R.J., May 13, 1905, p. 867. Heater, added to 35 locoomotives. G.E. bulletin 4537. |
| 105 | 71 | 29 | 4–6–4 | 1908 | Four truck wheels added. S.R.J., Dec. 19, 1908, p. 1620. |
| 115 | 72 | 36 | 4–6–4 | 1909 | Change in wheel base and frame for 12 new locomotives. Drive-wheel base, 13 feet, not changed. |

**The speed** for which the locomotives of the 2–6–2 wheel arrangement were designed was 60 m. p. h., but the locomotives were not safe at or beyond that speed, even on the good track and curves in the New York Central electric zone. The locomotives showed true nosing characteristics, at high speed until, in 1908, the 2-wheel radial pony trucks were changed to 4-wheel swivel bogey trucks, or to the 4–6–4 wheel arrangement. Too much motive power was concentrated on the 13-foot rigid wheel base.

The total wheel base was increased from 27 to 36 feet. Care was taken to keep the side-motion friction plates adjusted, to limit the nosing effect. A disastrous wreck occurred in March, 1907, when two locomotives were

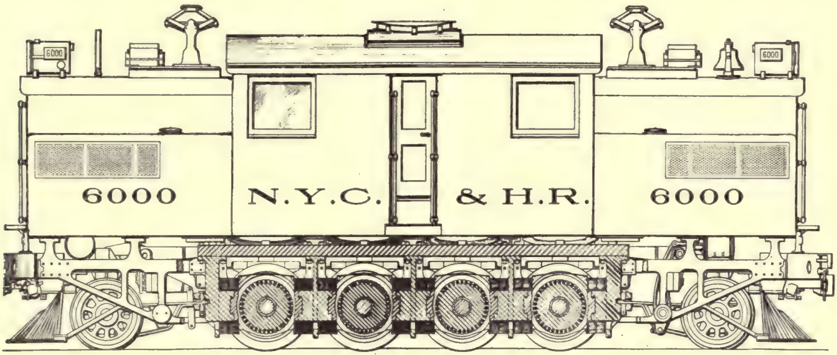


Fig. 92.—New York Central Locomotive.
Longitudinal section of the 1906 type.

hauling a train at high speed, and since that time two locomotives have not been used to haul one train.

The speed is now limited by the operating rules to 45 m. p. h. on straight track and 30 m. p. h. on curves.


Fig. 93.—New York Central & Hudson River Railroad Locomotive, 1908.

**Motors** consist of four, GE-84-A, gearless, 600-volt units per locomotive, rated 762 amperes each on the 1-hour rating. The accelerating current is 830 amperes. The locomotive rating is 2200 h. p. at 40 m. p. h.

and 20,500 pounds tractive effort with 44-inch drivers. The continuous rating is given as 1166 h.p. by Sprague, 1200 h.p. by Hutchinson, and 920 h. p. by Gibbs. Forced ventilation is not yet used.


FIG. 94.—NEW YORK CENTRAL & HUDSON RIVER RAILROAD LOCOMOTIVE, 1906.

The armature is placed directly upon the axle. The magnetic frames, carrying two pole pieces per motor, are part of the truck frame. The poles have nearly vertical faces and the armature has a large free vertical movement in a practically uniform clearance, without striking the poles.

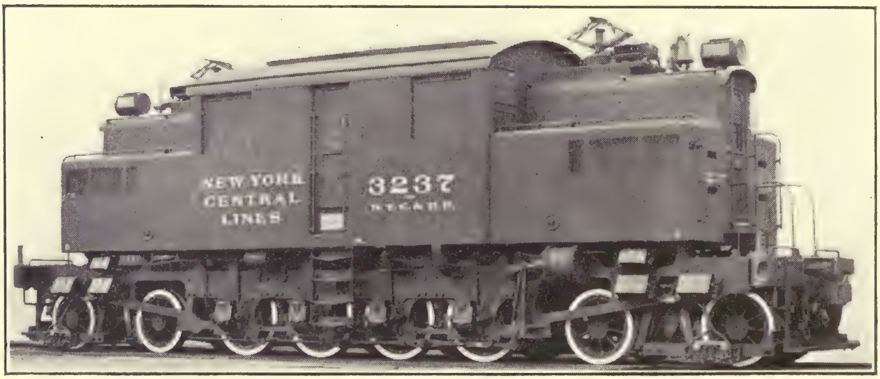


FIG. 95.—NEW YORK CENTRAL & HUDSON RIVER RAILROAD LOCOMOTIVE, 1909.

Weight of the motors is 37,700 pounds, plus 11,900 pounds for the magnet yoke, which is also the mechanical frame of the locomotive, making the total motor weight 49,600 pounds. To this is to be added 18,400 pounds for control equipment, rheostats, and wiring, and 4300 for air compressor. Total electrical weight, 36 tons or

about 31.4 per cent. of the total weight, 115 tons. Each armature and 8.5-inch axle weigh 7640 pounds. The core is 29 inches in diameter and 19 inches wide. This dead weight is not spring-mounted, but it is not unbalanced, as in the drivers of a steam locomotive. The total weight per driver axle is 36,000 pounds. The dead weight per axle is 13,000 pounds, to be compared with 7000 to 13,000 pounds for steam locomotives.

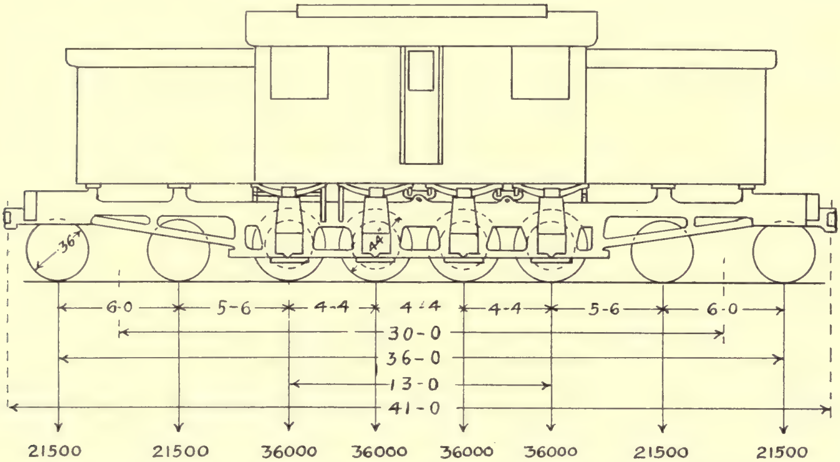


FIG. 96.—NEW YORK CENTRAL & HUDSON RIVER RAILROAD LOCOMOTIVE, 1908–1909. Forty-seven used on New York Division in passenger service. 115-ton, 2200-h. p., direct-current, 600-volts. 4 gearless motors. Axle mounted. Natural ventilation.

**Gearless motors** in this passenger locomotive service embody simplicity, strength, high efficiency, low maintenance cost, ease of inspection, and facility in making repairs. The armature with its wheels and axle can be removed, by lowering it, without disturbing the fields. The motor is neither waterproof nor enclosed, yet it does not hold water as in some enclosed types with forced ventilation.

**Center of gravity** of the locomotive was at first 44.4 inches above the rails; with the addition of the four leading wheels, it is now about 40 inches above the rails. The locomotive mass cannot swing, but must follow the rapid variations in the track, and the vertical and side springs which are used cannot ease the blow on the track. The cost of track and curve maintenance may therefore be much higher than usual.

**Tests** on No. 6000, 95-ton; 8-coach train, 336 tons, total 431 tons.

Nov. 12, 1904: Accelerating rate 0.33 m. p. h. p. s. required 1200 kw. at motor; voltage was 730; speed reached 63 m. p. h. in 280 seconds.

Apr. 29, 1905: Locomotive and one 42-ton coach attained a speed of 79 miles per hour. Acceleration rate with 6 coaches was 0.4 m. p. h. p. s.; voltage not specified.

Sept. 30, 1905: Acceleration of a 433-ton train, to 50 m. p. h., with 600 volts pressure, was at the rate of 0.43m. p. h. p. s.

October, 1905: Endurance test of 50,000 miles, hauling a train of 200 to 400 tons, over a 6-mile track. Maintenance expense, $0.014 per mile.

COST OF OPERATION, STEAM AND ELECTRIC LOCOMOTIVES. WILGUS.

| Item. | Steam locomotive. | | | Electric locomotive. | | |
|---|---|---|---|---|---|---|
| | Switching. | Transfer. | Road. | Switching. | Transfer. | Road. |
| Supplies | $8.06 | $1.12 | $2.03 | $6.88 | $1.16 | $1.37 |
| Wages | 5.34 | 0.35 | 0.28 | 5.25 | 0.31 | 0.31 |
| Interest, dep. and repairs. | 7.61 | 0.52 | 0.46 | 4.40 | 0.28 | 0.34 |
| Total | 21.01 | 1.99 | 2.77 | 16.53 | 1.75 | 2.02 |

COST PER YEAR FOR SERVICE.

| Item. | Steam locomotive. | | | Electric locomotive. | | |
|---|---|---|---|---|---|---|
| | Cost. | Rate. | Amount. | Cost. | Rate. | Amount. |
| Interest | $15,000 | 4.25% | $637.00 | $30,000 | 4.25% | $1275.00 |
| Depreciation | ......... | 5.00 | 750.00 | ......... | 5.00 | 1500.00 |
| Repairs | ......... | ........ | 1842.00 | ......... | ........ | 704.00 |
| Handling and inspection. | ......... | ........ | 1231.00 | ......... | ........ | 200.00 |
| Total | ......... | ........ | 4,460.00 | ......... | ........ | 3,679.00 |

Based on actual observations running over two to three years.
Tests for above, September and October, 1907. Wilgus, A. S. C. E., March, 1908.

PERFORMANCE CHARACTERISTICS OF PASSENGER LOCOMOTIVES.

| Current amperes. | Speed m.p.h. | Tractive effort lbs. | Power h.p. | Notes and conditions. |
|---|---|---|---|---|
| 4000 | 37.0 | 28,800 | 2840 | Four motors in multiple. |
| 3050 | 40.0 | 20,500 | 2200 | One-hour h.p. 2200. |
| 2000 | 48.0 | 11,200 | 1440 | Volts, 600. |
| 1500 | 57.0 | 6,700 | 1000 | Continuous h.p., 1000. |
| 1250 | 63.0 | 5,000 | 840 | Drivers 44-inch. |
| 1000 | 73.0 | 3,750 | 730 | G.E. bulletins 4390 and 4537. |

**Comparison** of New York Central electric locomotives with steam locomotives of a corresponding age and type:

| | % |
|---|---|
| Greater daily ton-mileage with electric locomotive | 25 |
| Saving in locomotive repairs about | 60 |
| Saving in locomotive repairs and fixed charges | 19 |
| Saving in dead time for repairs and inspections | 18 |
| Saving in locomotive ton-mileage in hauling service | 6 |
| Saving in locomotive ton-mileage in switching service | 11 |
| Saving in locomotive ton-mileage in road service | 16 |
| Net saving in cost of hauling service | 12 |
| Net saving in cost of switching service | 21 |
| Net saving in cost of road service | 27 |
| Net saving of terminal and yard operation, August, 1907 | 13 |

FIG. 97.—NEW YORK CENTRAL LOCOMOTIVE AND SEVEN-CAR TRAIN.

"In switching service, the economy of electric traction lies in savings for supplies, and in lower unit fixed charges and repairs due to less lost time for repairs and care.

"In slow-speed hauling, the advantages lie in the lower unit fixed charges and repairs of the electric locomotive, due to its ability to do more work while busy, and to less lost time for repairs and care.

"High-speed road service shows advantages for electric traction in all three items; supplies, wages, and fixed charges and repairs. The small 18 per cent increase in current consumption for the greater speed of road service, as compared with hauling service, is in marked contrast to the 165 per cent. increase in coal consumption for steam locomotives.

"The handling and inspection, including fixed charges and maintenance of land, structures, boiler, engine, and pumping plant for steam locomotives cost \$3.37 per day, while the same items for the electric locomotive which requires no roundhouse nor pumping plant to wash out flues, etc., but with its inspection sheds, cost but \$0.55 per day.

"Opportunities for large economies lie in the thoro training of motormen in the manipulation of their controllers, a very simple problem as compared with the difficulties of teaching both the engineer and firemen on steam locomotives to perform their duties so as to result in fuel economy." Wilgus: A. S. C. E., March, 1908.

**Economic results** also noted by Vice-President Wilgus:

"The net results of electrical operation over steam, for the conditions existing on the New York Central, would, after including all elements of cost of additional plant, show a saving in the summer months of from 12 to 27 per cent., depending upon the character of the service, while even a larger saving might be expected under winter conditions; that because of less cost of maintenance of electric equipment and less idle time in the repair shops, the greater cost of extra charges and depreciation for the system was not only neutralized, but a net saving of 19 per cent. on repairs and fixed charges over steam equipment was effected; that electric-locomotive inspection and lighter repairs, as compared with coaling, watering, drawing fires, etc., of steam locomotives showed a saving in time in favor of electricity of more than 4 hours per day, equal to 18 per cent.; and that the electric locomotive, when busy, was a much more nimble and efficient machine than the steam locomotive, showing an increase in daily ton-mileage of 25 per cent. The question of locomotive weight is a large factor in a comparison of relative economies in handling passenger traffic by steam and by electricity, and in the switch service at the Grand Central terminal 65 per cent. of the total steam ton-mileage was due to locomotive or dead weight, while the electric locomotive percentage was but 54 per cent." Martin, U. S. Census, 1907.

**Mileage** of electric locomotives in 1910 approximated 1,100,000 miles, or only 64 miles per day per locomotive owned. The suburban passenger service is handled largely by motor-car trains, the mileage of which in 1908 was 3,500,000 car-miles.

### References on New York Central Locomotives.

Potter and Arnold: Steam Locomotive Tests, A. I. E. E., June, 1902.
Proposed Locomotives: S. R. J., June 4, 1904.
Controversy on System and Cost: Mr. Westinghouse, Mr. Sprague, and others, S. R. J., and E. W., Oct. and Dec., 1905; Ry. Gazette, Dec. 22, 1905, p. 579.
Electric Locomotive Tests: S. R. J., Nov. 19, 1904; Jan. 21, 1905; May 13, 1905.
Locomotive Catechism and Operating Rules: S. R. J., Oct. 12, 1907, p. 565.
Wilgus: Steam versus Electric Power, S. R. J., Oct., 1904; A. I. E. E., Nov., 1907.
Locomotive Data: Ry. Age, June 30 and Nov. 18, 1904; Jan. 26, 1906.
Accident and Cause: S. R. J., March 16 and 30, 1907; Scientific American, March April, and May, 1907; Shearing of Spikes, E. W., March 16, 1907, p. 539.
Lister: Handling of Equipment, Ry. Age Gazette, June 3, 1910.

## MICHIGAN CENTRAL.

**Michigan Central Railroad** since July, 1910, has used six 100-ton electric locomotives between the Windsor, Ontario, yards and the Detroit yards. A double-track tunnel under the Detroit River, with grades of 1.4 and 2.0 per cent. for 2000 feet at each end of the tunnel, connects these yards. The length of the electric zone is 6, and the mileage is 19.

**Specifications** called for locomotives for freight and passenger service in the tunnel, and for switching service at the terminal yards. Two locomotives were to haul an 1800-ton trailing train thru the yards and tunnels and up a 4000-foot, 2 per cent. grade at 10 m. p. h., then after a layover of 15 minutes to repeat this trip, and so on continually without undue heating of motors.

**Design** is of the articulated type with two 4-wheeled, coupled trucks, 48-inch drivers, a rigid wheel base of 9.5 feet, and a total base of 27.5 feet. The trucks are not independent, but form a single articulated running gear.


FIG. 98.—MICHIGAN CENTRAL RAILROAD LOCOMOTIVE OF 1910.

"The system of spring suspension is of the locomotive type, the weight being carried on semi-elliptic springs resting on the journal box saddles. The system of equalization by which these springs are connected is interesting. The A end of the running gear, or what may be called the forward truck, is side-equalized, the two springs on each side being connected together through an equalizer beam. This equalizes the distribution of weight between the two wheels on one side, giving to this truck a 2-point support, and consequently leaving it in a condition of unstable equilibrium as regards tilting stresses—that is, stresses tending to tip the truck forward or backward. The B end of the running gear, or what may be called the rear truck of the locomotive, is cross-equalized, the two springs on the rear axle being connected together through an equalizer beam. The other two springs on this truck are independent and are connected directly to the truck frame. This results in a 3-point suspension on the rear truck, leaving it in a condition of stable equilibrium, capable of resisting stresses in any direction, whether rolling or tilting. The trucks are coupled together by a massive hinge, so designed as to enable the rear truck to resist any tilting tendency of the forward truck. This hinge combines the trucks into a single articulated running gear, having lateral flexibility with

vertical rigidity. Thus the running gear has what may be called a compound point suspension, while the forward and rear trucks together form an articulated frame having a 3-point suspension, consisting of the 2-point support of the forward truck and the independent equalization of the rear truck.

The draft rigging consists of a standard M. C. B. vertical plane coupler, with yoke, springs, and follower plates, designed to comply with the railroad company's specifications." E. R. J., June 19, 1909.

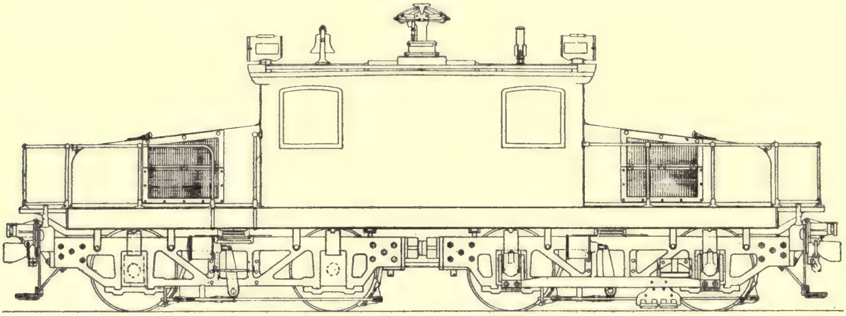

FIG. 99.—MICHIGAN CENTRAL RAILROAD. ELEVATION OF 1910 LOCOMOTIVE.

**Motors** per locomotive are 4, direct-current, 600-volt, 400-ampere G.E. 209-A, commutating-pole units. One-hour rating is 275 h. p. each, with a forced ventilation, at 2 1/4 inches water-gage pressure, of 400 cubic feet per minute. The continuous rating is about 123 h. p. Design of motor embraces 4 main poles, interpoles, a 3/16-inch air-gap, an armature diameter of 25 inches, a core length of 11.5 inches, with forty-one

FIG. 100.—MICHIGAN CENTRAL RAILROAD. ELECTRIC LOCOMOTIVE AT DETROIT RIVER TUNNEL HAULING 1400-TON FREIGHT TRAIN.

2x5/8-inch slots, for five 1-turn coils per slot, and .8x.08-inch conductors. Commutator diameter is 22.5 inches, segments 205, brush studs 2, and brushes three 2 1/4x2 1/2x1 1/16-inch per stud. Pinions are placed at each end of the armature shaft and there is a 4.37 reduction ratio.

Efficiency of motor including gear loss, at 12 m. p. h., 390 amperes,

and 600 volts, is 86 per cent.; it raises to a maximum of 88 per cent. at 14 m. p. h. and lowers to 83 per cent. at 10.5 m. p. h. Resistance of motor at 75° C. is 0.1 ohm. See motor drawings, Figure 43.

**Controllers** are Sprague-General Electric. Two or more locomotives are controlled from either end of any cab. Acceleration provided is particularly uniform, to prevent breaking the drawbars on ordinary 50-car freight trains. The motors are used 4 in series, 2 in series and 2 in parallel, or 4 in parallel. There are 9 resistance steps in series, 8 in series-parallel, and 7 in parallel.

**Weight** of armature is 3000; magnet frame, 3000; 4 main poles and spools, 1000; 4 interpoles and spools, 500 pounds; motor complete, 10,200; and with gear case 11,600 pounds; electrical equipment, 32 tons; dead weight per axle, 7 tons. Locomotive weight, 100 tons.

PERFORMANCE CHARACTERISTICS OF MICHIGAN CENTRAL LOCOMOTIVES.

| Current amperes. | Speed m.p.h. | Tractive effort lb. | Power H.p. | Notes or conditions. |
|---|---|---|---|---|
| 2400 | 10.7 | 56,000 | 1600 | Forced ventilation. |
| 2100 | 11.0 | 48,000 | 1410 | Volts 600. |
| 1600 | 11.8 | 35,000 | 1100 | One-hour h.p. 1100. |
| 1200 | 13.0 | 24,000 | 830 | ........................ |
| 1000 | 14.0 | 18,800 | 700 | Drivers 48-inch. |
| 900 | 14.5 | 16,000 | 620 | Gear ratio 4.37. |
| 835 | 15.0 | 14,400 | 575 | ........................ |
| 720 | 16.0 | 11,500 | 490 | Continuous h.p. 490. |
| 550 | 18.0 | 7,200 | 345 | ........................ |
| 440 | 20.0 | 4,900 | 260 | ........................ |
| 400 | 21.0 | 4,000 | 225 | Four G.E-209 motors. |

Baltimore & Ohio 1910 locomotives use this motor and gear, and 50-inch drivers.

**References:** Drawings in E. W., April 18, 1908; E. R. J., May 18, 1907; March 28, 1908; June 19, 1909; Jan. 14 and 21, 1911.

### PENNSYLVANIA RAILROAD—EXPERIMENTAL.

**Pennsylvania Railroad Company** in 1905 and 1907 ordered from the Westinghouse Company direct-current locomotives No. 10001 and No. 10002, a geared and a gearless type respectively. They were at first used on the Long Island Railroad and on the West Jersey and Seashore Railroad, for testing purposes, in freight and passenger haulage, and also in high-speed service. The design was a symmetrical swivel truck type.

Weight of the geared unit was 87 tons, and of the gearless, 97 tons. Rigid wheel base, 8.5 feet; total wheel base, 26 feet; drivers 56-inch.

Motors were two per locomotive, direct-current, 600-volt, rated 300 and 320 h. p. The gearless motor weight was 11,500 pounds and the armature weight 5300 pounds. Natural ventilation was used.


Fig. 101.—Pennsylvania Railroad Experimental Locomotive of 1905.

On test, at speeds above 45 m. p. h., the two-swivel-truck wheel arrangement was not safe, and track destruction was evidenced. Tests were continued with unsymmetrical trucks. See alternating-current locomotive, page 357.

**References.** S. R. J., Feb. 24, 1906, and Oct. 12, 1907, p. 602, plate XXI.

### PENNSYLVANIA RAILROAD, 1910.

**Pennsylvania Railroad Company** placed in service in 1910 at its New York Terminal Division, 24 direct-current, 157-ton, 4–4–4–4 type locomotives. Cabs, running gear, and mechanical parts were built by the Company, while the electrical equipment was Westinghouse. In 1911, nine duplicate locomotives were placed in service.

**The electric zone** in which these locomotives run extends 12 miles east from Newark, New Jersey, and thru two tunnels to the terminal in Manhattan, thence on east 4 miles and thru two tunnels to Long Island

City and to Sunnyside terminal yards beyond. The New York Connecting Railroad will make connections to the New Haven road via the Harlem River yards. Montauk Point trains between the New York terminal and points 25 miles east, on Long Island, are handled by electric locomotives; while motor-car train service, thru two other tunnels between Manhattan and Long Island, is handled by the Long Island Railroad. Motor-car train service between Newark, or Manhatten Transfer, and Jersey City, over Pennsylvania tracks, is handled by the Hudson and Manhattan Railroad. Sunnyside yards have 73 miles of tracks.

**The service** includes the handling by electric locomotives of about 88 thru passenger trains per day in the above electric zone.

**Specifications** outlined by the Pennsylvania Railroad locomotive committee, George Gibbs, A. W. Gibbs, D. F. Crawford, and A. S. Vogt, called for a 2-motor, double American-type articulated locomotive, which would start and accelerate a 550-ton trailing load (9 Pullmans) on 2


FIG. 102.—PENNSYLVANIA RAILROAD 157-TON LOCOMOTIVE OF 1910.

per cent. tunnel grades. It was to have a guaranteed tractive effort of 60,000 pounds for one-half minute and 50,000 pounds for two minutes. (On test a dynamometer between the locomotive and a train, with some brakes set, showed a drawbar pull of 79,200 pounds or 39 per cent. of the weight on the drivers.) The normal speed, with load on the level, was to be 60 m. p. h., yet the locomotive was to be safe at 80 m. p. h., for use on a New York-Philadelphia run. Tests called for acceleration of trains on a 2 per cent. grade with one motor cut out. Controllers were required to carry as high as 7000 amperes at 600 volts.

**Weight** of the locomotive is 314,000 pounds of which 200,000 pounds, or 64 per cent., are carried by 4 sets of 72-inch drivers, and 114,000 pounds by 4 sets of 36-inch bogie wheels.

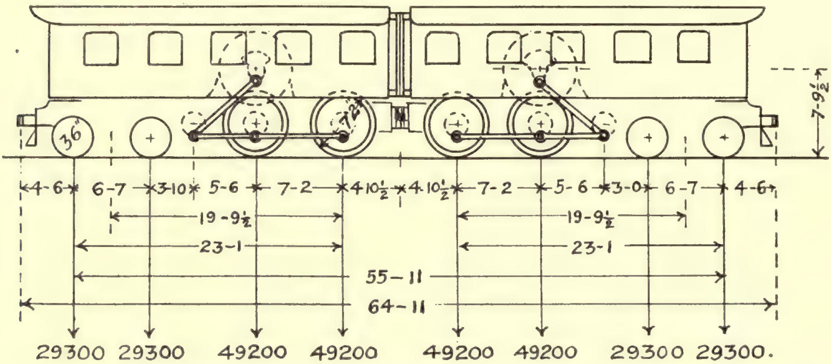


FIG. 103.—PENNSYLVANIA RAILROAD LOCOMOTIVE OF 1910.
Thirty-three used at New York terminal. 157-ton, 2500-h. p., direct-current, 660-volts. Two motors, side-rod type. Crank diameter 26 inches. Natural ventilation. Passenger service.


FIG. 104.—PENNSYLVANIA RAILROAD. FRONT ELEVATION OF LOCOMOTIVE.

In general the locomotive is built in two sections, with two symmetrical running gears, joined at the middle with a permanent coupling of twin drawbars and friction draft gears so designed that the leading half serves to guide the trailer, and opposes any buckling action of halves.

**Mechanical connections** are made by means of rods between cranks on the ends of the armature shaft of the motor and cranks on a jackshaft, which is mounted on the frames in the same plane as the driving axles.

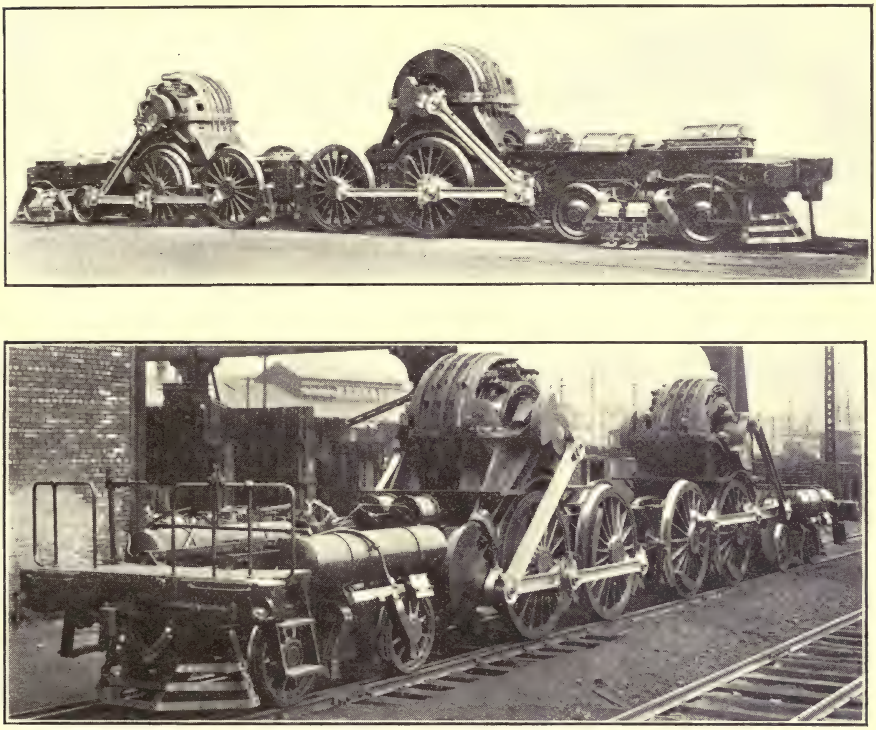

Fig. 105.—Pennsylvania Railroad. Running Gear of Locomotive.
The two motors are mounted on the truck frames.

Cranks are necessary, with the great length of the armature shaft used. The fixed distance between the center line of the jackshaft and the motor is 7 feet 2 inches. The jackshaft cranks connect to cranks on the drivers by means of 6-foot side rods. The cranks are in quartered positions, and counterbalanced. Connecting side rods, which run from the crank to the two drivers, have the adjustable heads employed on the Pennsylvania class E-3 steam locomotive.

**Trucks** are two, of the articulated type. Truck wheel bases are 6 feet 7 inches; rigid driver wheel bases, 7 feet 2 inches; wheel base of each half,

23 feet 1 inch; total wheel base, 55 feet 11 inches. Locomotive length over all is 65 feet.

The center of gravity is 64 inches above the rail.

**Frames** are of cast steel and of sufficient strength to allow the engine to be raised by jacks applied at fixed points, with all pedestal binders removed. The side frames are broad, and furnish bases for the feet of the electric motor frames, which fit over the heavy flanged top members of the side frames. The frames are proportioned for a bump equivalent to the static load of 500,000 pounds (150,000 pounds applied on the center line of draft cylinders and 350,000 pounds applied on the center line of platform buffers) which is to produce no stress in the frames exceeding 12,000 pounds per square inch.

**Motors** consist of two direct-current interpole units per locomotive. The 1-hour rating on 600 volts and 1350 amperes is 1000 h. p. with natural ventilation; on 660 volts and 1525 amperes is 1250 h. p.; and the continuous rating on 660 volts and 1070 amperes is 800 h. p. Motors are guaranteed to handle the tunnel and terminal service and train weights on the grade, with given layover periods. Two motors can develop 4000 h. p. for 30 minutes. The intermittent character of the service calls for a root-mean-square all-day load of 1600 amperes at 400 volts, at which load the rise in temperature will not exceed 60° C.

The armature is 56 inches in diameter, and the core is 23 inches wide. The speed at 60 m.p.h. is 280 r.p.m. The armature core is so mounted on the spider that in case of a short circuit or flash-over, between the brush holders, which would act as an electric brake on the armature, the core will slip on an adjustable clutch on the armature spider, and prevent the destruction of crank pins or locomotive driving mechanism. Bearings do not extend under the commutator or under the armature windings, and caps may be lifted vertically. The center line of the motor armature is 25 1/2 inches above the cab floor, and 93 1/2 inches above the rail, and thus the motor is secure from snow, dirt, and water. Space limitations are largely removed and the design possesses excellent mechanical and electrical features. The motor shaft extends well across the width of the cab giving room for ample bearing length. The motor frames are cast-steel shells, divided horizontally. Natural ventilation is used. Each motor weighs complete, with the crank, 45,000 pounds and the armature weighs 10,950 pounds. See figure 49.

**Controllers** of the electro-pneumatic switch type, *i. e.*, actuated by air from the brake compressor and operated by electro-magnets, are placed at each end of the cab. The main power does not pass thru the controllers or the cab. Three speeds are called for in control, a slow speed for switching operations, half speed, and full speed. The bridging scheme is used for passing from series to multiple connection. Motor fields are reversed to change the direction of motion.

**Field control** is used on the two motors in addition to the series-multiple grouping, and a large saving is thus effected in resistors. During acceleration the power consumption is reduced to 55 per cent. of what it would be without field control. The design of the poles is such that

each is wound in 2 sections, the full field being shunted for high speed. The change from full field to normal field increases the speed 65 per cent. and reduces the tractive effort 39 per cent., the motor horse power being

FIG. 106.—PENNSYLVANIA RAILROAD LOCOMOTIVE AND EIGHT-CAR TRAIN.

FIG. 107.—LOCOMOTIVE HAULING THE NEW YORK-CHICAGO, 18-HOUR, "PENNSYLVANIA SPECIAL."

at 1000. A motor load of 1250 h. p. is developed with the normal field without appreciable sparking; and, when running at 70 m. p. h., on 725 volts, with normal field, the opened and closed circuits caused by gaps in the third rails do not cause spitting at the brushes.

Switches and control devices must handle very heavy current inputs, commonly 7000 amperes at 660 volts and in emergency as high as 9000 amperes. Power-plant switchboards seldom handle such heavy currents and they are never operated so many times as on a locomotive. The efficiency of these switches, which are able to rupture the entire current, is remarkable. Altho the noise somewhat resembles the report of a pistol, there is hardly a flash on the arcing tips.

### PERFORMANCE CHARACTERISTICS OF THE PENNSYLVANIA LOCOMOTIVES.

Volts, 600; drivers, 72-inch; air gap, 9/16-inch; crank diameters, 26 inches; motors in parallel; transmission losses not included. Data from Westinghouse publication; Electric Journal; articles by George Gibbs, J. L. Davis; and other sources.

| Speed m.p.h. | Current amperes. | Power h.p. | Efficiency p.c. | Tractive effort pounds. | Field winding. |
|---|---|---|---|---|---|
| 0 | 7000 | ............ | ............ | 79,200 | Full. |
| 24 | 6400 | 4400 | 85.0 | 69,000 | Full. |
| 25 | 5700 | 4000 | 87.0 | 60,000 | Full. |
| 26 | 4700 | 3360 | 89.0 | 48,000 | Full. |
| 31.5 | 2700 | 2000 | 92.2 | 24,000 | Full. |
| 36 | 2050 | 1540 | 93.0 | 16,000 | Full. |
| 40 | 4200 | 3100 | 92.0 | 29,400 | Normal. |
| 44 | 3500 | 2600 | 93.0 | 22,000 | Normal. |
| 50 | 2800 | 2120 | 93.5 | 16,000 | Normal. |
| 52 | 2650 | 2000 | 93.5 | 14,600 | Normal. |
| 60 | 2100 | 1600 | 93.5 | 10,000 | Normal. |
| 70 | 1700 | 1280 | 93.0 | 7,000 | Normal. |
| 76 | 1500 | 1120 | 92.5 | 5,500 | Normal. |

Operating voltage is 660, on which there is 10 per cent. greater speed and power.

**Service** during 1910 has shown the following:

Work on the tunnel grades is severe, and at high speed the air resistance in the long tubes is excessive.

Locomotive loads of 10 cars in switching and storage service, and 13 cars in regular passenger trains have been hauled.

Clutches between the armature core and the spider of the motor are set to slip at 3500 amperes per motor, and when they have slipped they have caused no delay.

Acceleration often requires 2700 amperes.

The rear half of the locomotive does not seem to articulate well with the front half. Some action tends to lift the rear half from the tracks.

In acceleration the wheels seem to spin readily on the rear half.

Vibration of the entire locomotive is excessive, and has caused a great deal of breakage at wire terminals, couplings, and unions; loosening of the tightest bolts and nuts; breaking of rheostat grids; loosening of contactor fingers; shaking off of train line control jumpers; and opening of joints at heavy electrical connections.

Jackshaft design has not been satisfactory. The weight of the counterbalance has been increased, but the jackshaft persists in pounding. The jackshaft bearings and linings have also given trouble.

Smooth running has not been obtained. The locomotives are known as rollers and pitchers and have many of the qualities of modern steam locomotives in heavy high-speed-service.

**References.**

E. R. J., Nov. 6, 1909; Ry. Age, Nov. 5, 1909.
Scientific American, Dec. 18, 1909.
Kirker: Electric Journal, Sept., 1910.
Gibbs: E. R. J., June 3, 1911, p. 960.


FIG. 108.—GALT, PRESTON & HESPLER LOCOMOTIVE, 1910.

## GALT, PRESTON & HESPLER.

**Galt, Preston & Hespler Railway** locomotive is a good representative light-weight, inexpensive unit of the two-swivel-truck type with four 100-h. p., 50-ton, geared, 600-volt, direct-current motors, for light freight train service between small cities. Scores of similar locomotives are used by interurban railways.

## ILLINOIS TRACTION.

**Illinois Traction Company** has built about 6 locomotives per year since 1907 for its freight service in Illinois where it has about 560 miles of track.

The locomotives are of the 2-truck, swivel type, and resemble a common baggage car. They weigh 40 tons to 60 tons, and have a length

of 31 to 34 feet. Eight 36-inch drivers are used. Trucks and motors are purchased, but the locomotive frames are built by the company. The frames generally consist of six parallel 10-inch 40-pound I-beams, which

FIG. 109.—GALT, PRESTON & HESPLER LOCOMOTIVE AND 1050-TON TRAIN.

are continuous from bumper to bumper. The body framing is of structural steel shapes, and supports a turtle-back roof. Details follow the specifications of the M. C. B. Association, in the matter of roof, mounts, sliding doors, steps, footholds, couplers, draft gear, wheels, axles, pilots,

FIG. 110.—ILLINOIS TRACTION COMPANY LOCOMOTIVE OF 1910.
Six used in freight service on St. Louis Division. 60-ton, 960-h. p., direct-current, 600 volts. Four-geared motors, natural ventilation.

automatic air brakes, train pipes, etc. Truck wheel bases are 7 feet 2 inches, and truck centers of 19 feet are used. The inside of the locomotive is fairly free from apparatus, and is loaded with merchandise.

Motors are direct-current 600-volt. For the older locomotives, there are four 90- to 150-h. p. motors. Six locomotives built in 1910 have 4 G.E. 66-C, 240-h. p. motors, geared for slow speed, and controlled by Sprague-G.E. 18-point controllers, with 39 contactors.

**References.** Description, drawings, and photographs, S. R. J., March 16, and July 6, 1907; E. R. J., Oct. 8, 1910, p. 646.

### NORTH-EASTERN RAILWAY.

**North-Eastern Railway,** Newcastle, England, since 1904 has used six locomotives which displaced steam locomotives for freight traffic.

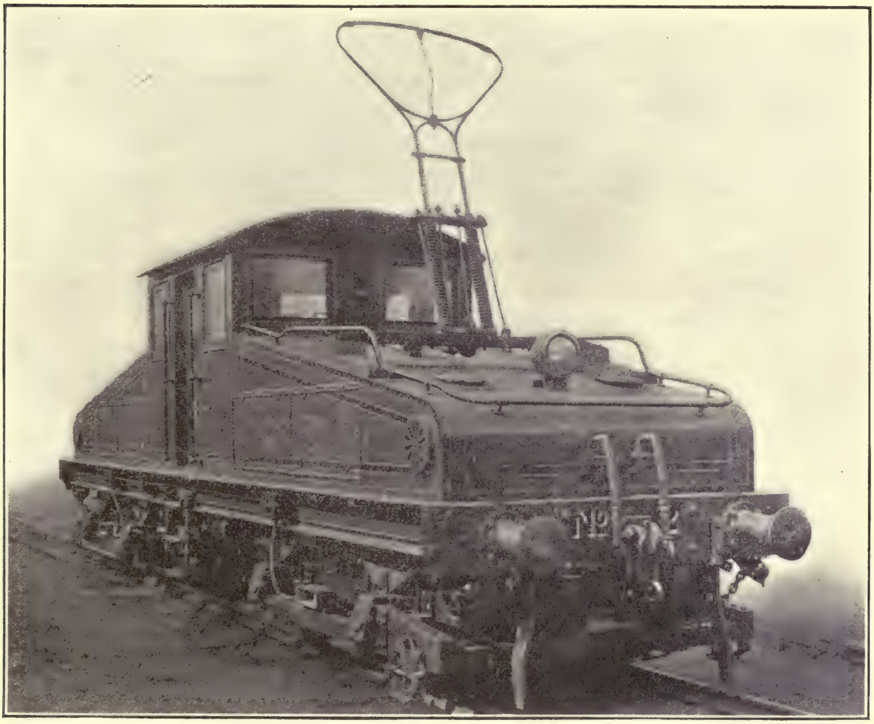

FIG. 111.—NORTH-EASTERN RAILWAY, ENGLAND, ELECTRIC FREIGHT LOCOMOTIVE.

The service and specifications require each locomotive to be capable of handling a 335-ton train on a level at 14 m. p. h. and of starting a 166-ton train on a 4 per cent. grade and running up this grade at 9.5 m.p.h. The electric locomotives are of the double bogie type with central cab.

Frames are of steel section with cast-iron blocks to bring up the weight. Side soles are 12-inch girders; center longitudinal girders are two 8-inch

channels, and ends are 15-inch channels. Head stocks are of 8x15-inch oak. The bolster is formed by two 6x5-inch girders, of 1-inch section, held on upper and lower sides by 3/4-inch plates.

Trucks are of steel-plate frame, in accordance with English railway practice, strengthened with steel angles, and gussets with swinging bolster. The latter is supported on two nests of coil springs and is provided with cast-steel wearing plates, cast-steel center and side-bearing plates. Side frames are supported on axle boxes by heavy laminated springs.

Motors are 4, a direct-current type, 600-volt, 160-h. p., with 2-turn armatures, and have a 3.28 gear ratio.

Weight is 55 tons, all on eight 36-inch drivers. Length is 38 feet and the truck pivoted centers are 20 feet 6 inches. Wheel base is 6 feet 6 inches.

**Reference.** S. R. J., Oct. 8, 1904, p. 675 with photograph.

### METROPOLITAN—LONDON.

**Metropolitan Railway** of London has used 10 electric locomotives for hauling the Great Western trains thru the northern part of the Circle, and for conveying its freight and passenger trains since the year 1905. The locomotives are used to haul 170-ton passenger trains at 36 m. p. h., and 275-ton freight trains at 27 m. p. h.

The framing resembles that on the North-Eastern. Two trucks are used, each with a 7-foot 6-inch wheel base. The truck centers are 17 feet 4 inches. Drivers are 36 inches. Total weight is 52 tons.

Motors per locomotive are 4, each 200 h.p., direct-current, 600-volt, but rated 250 h. p. with forced draft at 4 to 6 ounces pressure.

**Reference.** S. R. J., Aug. 26, 1905; Sept. 7, 1907.

### PARIS-ORLEANS RAILWAY.

**Paris-Orleans Railway** of France, a steam road, began the use of 8 electric locomotives in 1899, first on a 2.4-mile tunnel section, and in 1904 on a 15-mile section between Paris and Juvisy. Other sections have since been added.

The first locomotives were 55-ton, 35-foot, of the 2-bogie truck type with 4 sets of 49-inch drivers. Truck centers were 16 feet; truck bases 7 feet 10 inches, and the total wheel base 23 feet 10 inches.

Three 61-ton locomotives of the "baggage carrying" type with 18-foot 6-inch truck centers were added in 1904.

Service conditions require the locomotive to haul 220-ton trains at a schedule speed of 43 to 48 m. p. h. and at a maximum speed of 62 m. p. h. The balance speed on the level with a 300-ton trailing load is 32 m. p. h.

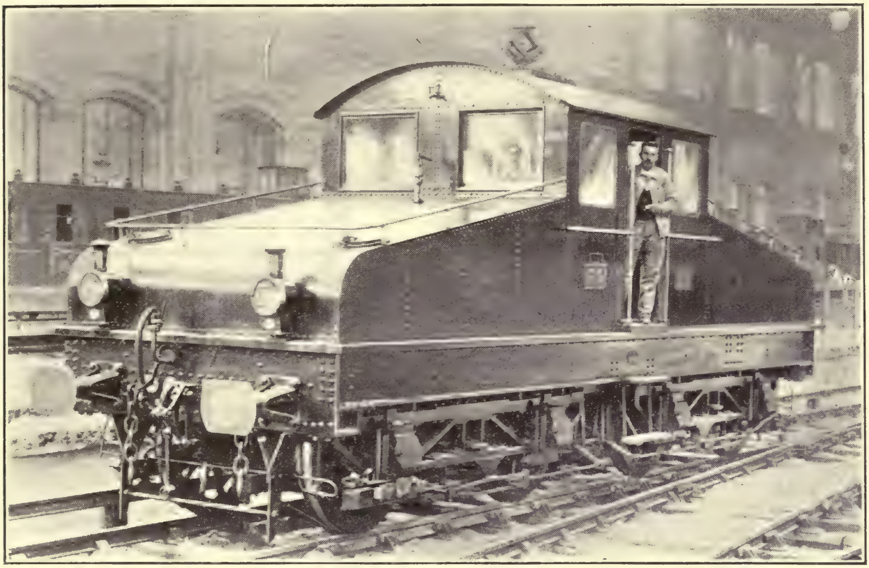

Fig. 112.—Paris-Orleans Railway Locomotive in Austerlitz Station, 1899.

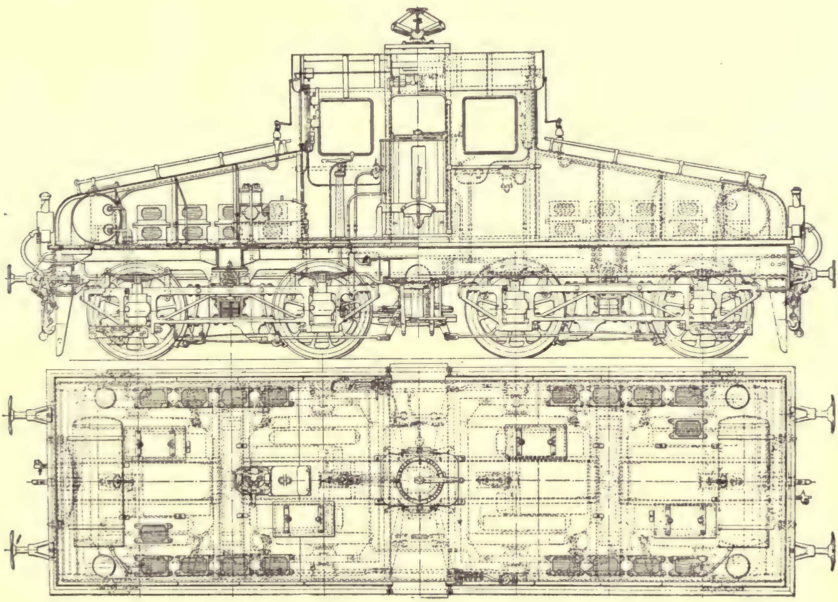

Fig. 113.—Paris-Orleans Railway Locomotive. Type used Since 1899.
Elevation and plan of 55-ton unit.

Motors on each locomotive are four G.E.-65, or 250-h. p., 575-volt, direct-current. The armature core is 23 1/2 inches in diameter by 12 inches long. The motors, which weigh 8855 pounds each, are mounted with one end on the axle and nose supported on the truck transom; and a 2.23 gear ratio is used. Weight of the electrical equipment is 39 per cent. of the total weight of the locomotive.

### DIRECT-CURRENT LOCOMOTIVES, 2000-VOLT.

**Rombacher-Huette Company** of Maizieres, Lorraine, France, has used 3 Siemens-Schuckert 2000-volt, direct-current, freight locomotives, since 1906. The road is 9 miles long and connects the Moselheutte blast furnaces with iron mines at Ste. Marie.

The service calls for the handling of 3000 tons of iron ore per day over a mountainous road. The ore is hauled up grades averaging 2 1/2

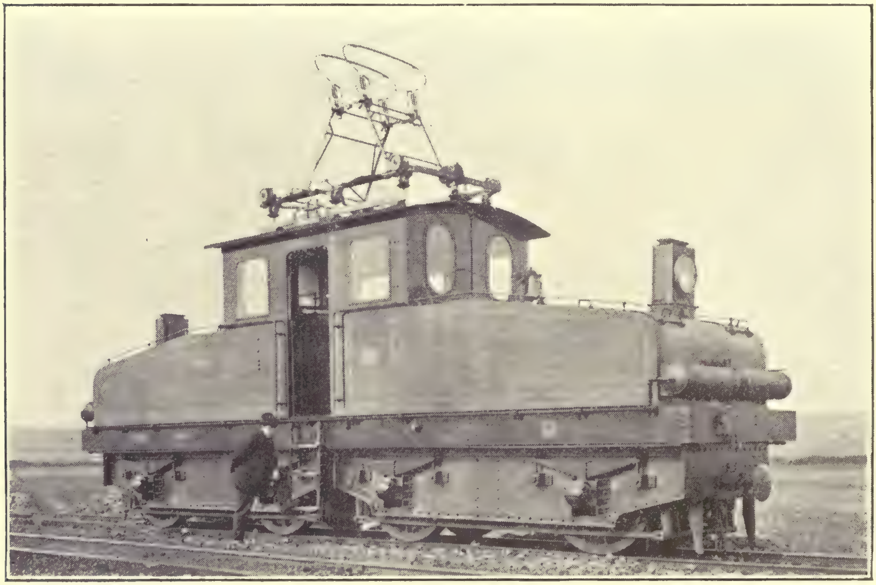

FIG. 114.—ROMBACHER HUETTE RAILWAY, MAIZIERES, FRANCE. FREIGHT LOCOMOTIVE.

per cent. for 2 miles, then a level stretch of 2 miles and then a downgrade averaging 2 1/2 per cent. for 5 miles. Ruling grades for loaded trains are 3 per cent. The curves are severe and require slow running. The trip requires one hour. Cars weigh 14 tons empty and 48 tons loaded. Trains weigh about 300 tons.

Locomotive weight is 62 tons, on 4 sets of 49-inch drivers. There are two 4-wheel bogie trucks on 15-foot 9-inch centers, and wheel bases of 8 foot 6 inch.

The power system used is as follows: Three-phase current is generated and transmitted at 5700 volts, and afterward converted to direct current. Three-phase traction was not used because it required complicated overhead construction, and a large number of substations. Single-phase traction at 6000 volts would have been a disadvantage, because the line was short; and because, with the meter gage used, and the long commutator and the shorter effective core length, a sufficiently large geared motor could not be placed below the locomotive platform.

Substations are located at each end of the line, and each contains a synchronous, three-phase, 880-h. p., 375-r. p. m. motor driving a 600-kw., 2000-volt, direct-current generator. Special care was given to the insulation of the commutator of the generator and motor; and brush holders are set in compartments and insulated from the brush rocker, which in turn is insulated from the frame. Commutating poles are provided. In the switch gear at the station and on the locomotives the air spaces provided are large. Blow-out coils send the arcs at the fingers outward along contacts arranged in the form of horns. Automatic cut-outs and fuses have reliefs thru the roof to give a free exit for the arc. Oil switches could not be used, because of the surging which would be produced in the high-tension, continuous-current system by the rapid extinction of the arc in the oil. Magnetic blow-outs use horn extinguishers, and the arc is broken at two points, well removed from the contact blades.

A short-circuit switch is provided in the cab, as on some American locomotives, for earthing the current collector, for the double purpose of protecting men who may be inspecting or repairing the electrical equipment and to short-circuit the main line in case an arc in the internal wiring, or in the motor, becomes uncontrollable.

Motors consist of four 160-h.p., 1000-volt, 4-pole, interpole, geared units, permanently connected in groups of 2 in series. Motors have 61 slots and 183 segments. At 160-h. p. rating, torque is 1700 pounds, speed is 620 r. p. m., amperes are 125, and motor efficiency is 91 per cent.

**Reference.** Railway Gazette, London, October and November, 1907.

**St. Georges de Commiers a la Mure,** France, a similar electric freight road, 20 miles long, was built in 1903.

The system is the direct-current, 2400-volt, Thury, 3-wire, 2-trolley. Locomotives weigh 55 tons and haul thirteen 44-ton cars up 2.75 per cent. grades. There are four 125-h.p., 600-volt, nose-suspended motors per locomotive. Electric braking is used.

**Reference.** S. R. J., Oct. 31, 1903. See 750- to 2000-volt roads, Chapter IV.

## LITERATURE.

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Havana Central R. R.: 40-ton, E. W., April 15, 1909.

Boston Elevated Ry.: S. R. J., March 2, 1907.

Canadian Pacific R. R.: Hull-Aylmer Div., freight, E. E., Oct. 7, 1896.

Brooklyn Rapid Transit: S. R. J., March 23, 1907, p. 488; Oct. 1, 1910; Ry. Age, Nov. 11, 1910.

Lackawanna & Wyoming Valley: S. R. J., Aug. 4, 1906.

Toledo & Indiana R. R.: S. R. J., Aug. 4, 1906.
Indiana Union Traction: E. R. J., Sept. 12, 1908, pp. 637 and 747.
Chicago City Railway: E. R. J., Nov. 21, 1908; E. T. W., Nov. 14, 1908.
Kansas City and Westport: S. R. J., Feb. 16, 1907.
Portland, Oregon, Railway: 7 locomotives, E. R. J., Dec. 21, 1907.
Northern Electric Ry., Cal.: E. R. J., June 10, 1911, p. 1011.
Pacific Electric Ry.: Los Angeles, E. R. J., Oct. 10, 1908, p. 827.

General Electric: Catalog No. 4537, Sept., 1907; No. 3287, Jan., 1905; No. 9139, Aug., 1905; No. 4390, Oct., 1904; No. 4851, June, 1911.
Westinghouse Electric Circular: No. 7045, of 1906; 1510 of 1910; 1517 of 1911.
Westinghouse and General Electric Data, E. R. J., July 2, 1906, p. 12.

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City and South London: S. R. J., June, 1899; Aug. 16, 1909, p. 229.
Norwegian: Electric Review, Nov. 13, 1909.
France: DuBois, S. R. J., May 20, 1905, p. 911.
Paris-Lyons Mediterranean: 600-h. p. loco. drawings, E. W., Feb. 4, 1899.
Vienna City: 520-h. p.; 1500-volt, d. c., 3-wire, S. R. J., Nov. 3, 1906.
See 1200- to 2000-volt railway references, pp. 129 and 130, Chapter IV.

## REFERENCES TO DETAILED DRAWINGS OF ELECTRIC LOCOMOTIVES.

| Name of Locomotive. | Maker. | Location. | References. |
|---|---|---|---|
| Baltimore & Ohio 96 | G.E. | Baltimore | |
| Baltimore & Ohio 03 | G.E. | Baltimore | G.E. Bulletin 4537, 1907, p. 12. |
| Baltimore & Ohio 10 | G.E. | Baltimore | G.E. Review, Dec., 1910. |
| Bush Terminal | G.E. | Brooklyn | G.E. Bulletin 4537, 1907, p. 14. |
| Brooklyn Rapid T. | Co | Brooklyn | S.R.J., March 23, 1907, p. 489. |
| Boston Elevated | Co | Boston | March 2, 1907, p. 388. |
| New York Central | G.E. | N. Y. Terminal | A.I.E.E., May, 1907, p. 748.<br>G.E. Bulletin 4537, 1907, p. 6.<br>S.R.J., Dec. 19, 1908, p. 1620. |
| Michigan Central | G.E. | Detroit | G.E. Bulletin 4537, p. 9. |
| Pennsylvania R.R. | West. | N. Y. Terminal | Ry. Age Gaz., Nov. 5, 1909. |
| Illinois Traction | G.E. | Illinois | E.R.J., Oct. 8, 1910. |
| Pacific Electric | West. | Los Angeles | E.R. Rev., July 27, 1907. |
| Northern Elec., Cal. | West. | Sacramento | E.R.J., June 10, 1911, p. 1011. |
| Metropolitan | T.H. | London | S.R.J., Aug. 26, 1905; Sept. 7, 1907. |
| Paris-Orleans | G.E. | France | |
| Paris-Lyons-M | | Paris Terminal | E. W., Feb. 4, 1899, p. 146. |
| Rombacher-Huette | Siemens | France | Ry. Gaz., Oct. and Nov., 1907. |

*This page is reserved for additional references and notes on direct-current locomotives.*

# CHAPTER IX.

## TECHNICAL DESCRIPTION OF THREE-PHASE LOCOMOTIVES.

### Outline.

LIST OF THREE-PHASE ELECTRIC LOCOMOTIVES.

| Name of railway. | Mileage. | Year opend. | No. of loco. | Power h.p. | Wt. tons. | Sets of drivers. | Speed m.p.h. | Gear ratio. | Voltage. | No. of cycles. |
|---|---|---|---|---|---|---|---|---|---|---|
| Lugano, Italy.... | 5 | 1896 | 1 | 25 | 5 | 2–33″ | 9 | 4.0 | 500 | 40 |
| Gornergrat....... | 6 | 1898 | 1 | 160 | 11 | Rack... | 4 | 12.0 | 500 | 40 |
| Jungfrau:....... | 10 | 1898 | 3 | 180 | 13 | Rack... | 5 | ....... | 500 | 38 |
| | | | 2 | 240 | 14 | ........ | 5 | 12.6 | 500 | 38 |
| Stansstad-Engleberg. | 14 | 1898 | 3 | 150 | 16 | Rack... | 3-6 | 5.0 | 750 | 33 |
| Burgdorf-Thun | 25 | 1899 | 2 | 170 | 32 | ........ | 24 | 3.00 | 750 | 40 |
| Interurban. | | | 1 | 300 | 33 | 2–48″ | 11 | 1.88 | 750 | 40 |
| Siemens Works .. | ...... | 1904 | 1 | 1000 | 44 | 6–35″ | ........ | 2.13 | 10000 | 50 |
| Italian State: | | | | | | | | | | |
| Valtellina Line | 70 | 1902 | 2 | 900 | 52 | 4–55″ | 19 | Crank | 3000 | 15 |
| | | 1904 | 2 | 1200 | 69 | 3–59″ | 38 | Crank | 3000 | 15 |
| | | 1906 | 2 | 1500 | 69 | 3–59″ | 40 | Crank | 3000 | 15 |
| Giovi Line, Genoa | 26 | 1909 | 20 | 1980 | 67 | 5–42″ | 28 | Crank | 3000 | 15 |
| | | | | | | | ........ | | | |
| Savonna Line... | 16 | 1909 | 10 | 1980 | 67 | 5–42″ | 28 | Crank | 3000 | 15 |
| Mt. Cenis Tunnel | 5 | 1910 | 10 | 1980 | 67 | 5–42″ | 28 | Crank | 3000 | 15 |
| Zossen Tests..... | 6 | 1903 | 1 | 1000 | 100 | 6–49″ | 120 | No gear | 10000 | 50 |
| (motor cars)... | 6 | 1903 | 1 | 1000 | 85 | 6–49″ | 120 | No gear | 10000 | 50 |
| Port Stanley, London, Canada | 27 | 1905 | 2 | 130 | 20 | 4–36″ | 30 | 3.27 | 1100 | 25 |
| Swiss Federal: | | | | | | | | | | |
| Simplon Tunnel. | 14 | 1907 | 2 | 1100 | 70 | 3–61″ | 43 | Crank | 3000 | 16 |
| | | 1909 | 2 | 1700 | 76 | 4–49″ | 43 | Crank | 3000 | 16 |
| Santa Fe, Spain.. | 15 | 1908 | 5 | 320 | 30 | 2 | 16 | Gear | 5500 | 25 |
| Great Northern: | | | | | | | | | | |
| Cascade Tunnel. | 7 | 1909 | 4 | 1700 | 115 | 4–60″ | 15 | 4.26 | 6600 | 25 |

**References** to detailed Drawings of Three-phase Locomotives, 353.

## CHAPTER IX.

# DESCRIPTION OF THREE-PHASE LOCOMOTIVES.

The technical descriptions of three-phase locomotives which follow do not include the small units used in the first five roads.

### SIEMENS-SCHUCKERT.

**Siemens-Schuckert Works,** in 1904, built a large 3-phase, 50-cycle, 44-ton locomotive, for experimental work. See accompanying illustration.

The locomotive had two bogie trucks, on the axles of which were four 6-pole, 250-h. p. geared motors. A 2.13 gear ratio was used. Drivers were 36-inch. The potential between each of 3 trolleys was 10,000 volts.

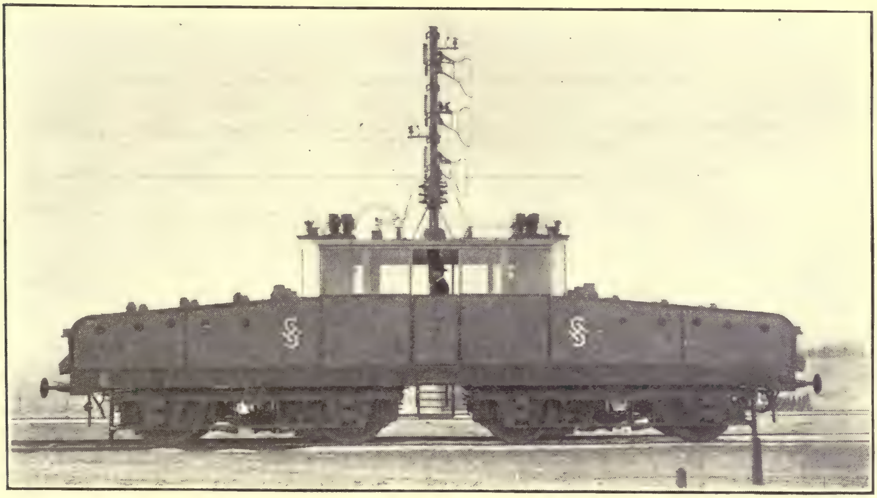

Fig. 115.—Siemens-Schuckert Locomotive of 1904.
Three-phase, 11,000- to 1000-volt, 1000-h. p., geared type.

### VALTELLINA RAILWAY.

**Valtellina Line** of the Italian State Railway, between Lecco, Sondrio, and Chiavenna, uses electric locomotives for 500-ton freight trains, and motor cars for 6-coach passenger trains. About 60 per cent. of the route has 2 per cent. gradients, tunnels, and sharp curves.

The system is the 15-cycle, 3000-volt, three-phase; and the road, which has 70 miles of track, is fed from a 4200-kw. water power plant, thru nine 300-kw. transformer substations.

The electrical equipment, built by Ganz & Company, follows:

Two 600-h. p., 52-ton, 0-4-0 locomotives ordered in 1902.

Two 1200-h. p., 69-ton, 2-6-2 locomotives ordered in 1904.

Two 1500-h. p., 69-ton, 2-6-2 locomotives ordered in 1906.

Ten 300- to 600-h. p., 32- to 58-ton motor cars, ordered in 1902.

**The 1902 locomotives,** with 2 swivel trucks and 4 pairs of drivers, are used for freight service. They have one economical speed, 18.6 miles per hour. Drawbar pull is rated 11,000 pounds. There are four 14-pole, 128 r.p.m., 150-h.p., gearless, axle-mounted motors per locomotive. Motors weigh 22 tons, or 42 per cent. of the total weight.

**The 1904 locomotives** have 3 driving axles and 2 pony axles. There are two economical speeds, 37.0 and 18.3 m.p.h., and the rated drawbar pull is 7000 to 12,000 pounds.

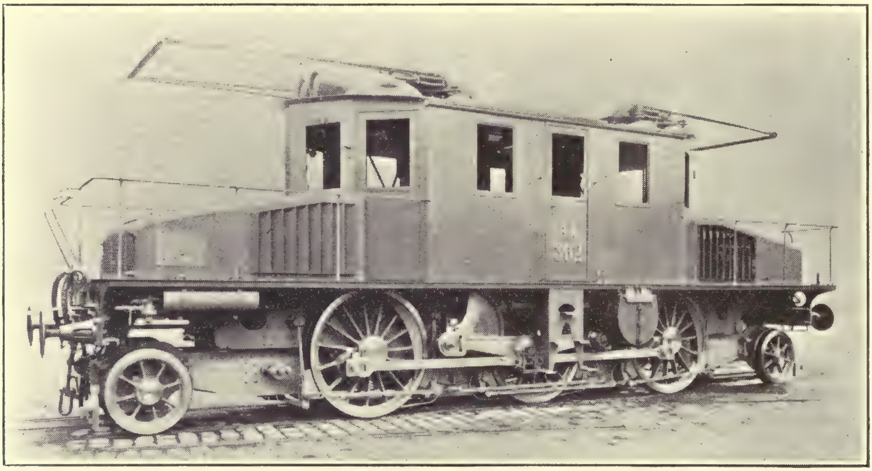

FIG. 116.—ITALIAN STATE RAILWAY,—VALTELLINA LOCOMOTIVE OF 1906.
Three-phase, 15-cycle, 2-motor unit. Total rated horse power 1500 at 40 m.p.h. Weight 69 tons.

**Motors** are two 600-h. p. twin units, mounted in pairs on one shaft between the second and third and between the third and fourth axles; and drive the axles thru a Scotch yoke, crank, and side rods. The 3 pairs of drivers are coupled and there is no danger, with varying loads on the individual motors, that one of the driving axles will slip. Motor and driving gear are spring-mounted and completely counterbalanced. Control is so arranged that at half speed the rotors of the 2 primary 3000-volt motors feed the stators of the two 400-volt motors connected in cascade relation with the first motors, which are placed on the same shaft. Each pair of motors has a 1-hour rating of 900 h. p. At full speed the 2 pairs of motors have a 1-hour rating of 1200 h. p. Width of motors is 51 inches, and diameter is 68 inches. Weight of two 600-h. p. primary motors is 36,800 pounds and of secondary motors 18,800 pounds; total 55,600 pounds or 40 per cent. of the total weight, which is 139,000 pounds. Distance between cranks along the axle is 78 inches; distance between axle bear-

ings along axle is 57 inches; distance between motor bearings along axle is 34 inches; width of motor is 51 inches; diameter of motor is 68 inches.

**Specifications** for the 1904 locomotive required it to accelerate a 448-ton train at 0.34 m. p. h. p. s., and to start a 448-ton train on a 0.3 per cent. grade, and bring it up to a speed of 18.6 m. p. h. every 2 minutes for 1 hour, without excessive heating; and further that the motors on 10-hour shop test, at rated speed and load, should not have a temperature rise in any part exceeding 60° C. above the surrounding air. A 100 per cent. overload was specified for 200 seconds, and also a 50 per cent. overload for 60 minutes, without 40° C. rise above the surrounding air.

**Design of 1904 locomotives** calls for one fixed middle axle, which is journaled in the main frames. The other two driving axles have a range

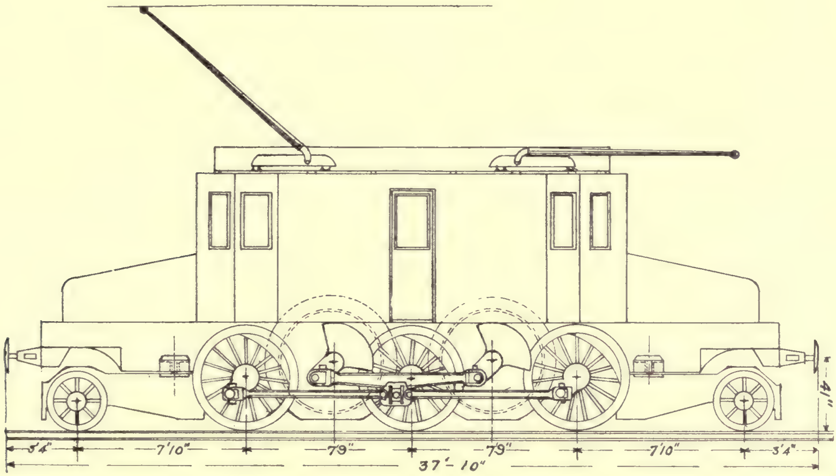


FIG. 117.—VALTELLINA RAILWAY LOCOMOTIVE OF 1906.

of side movement of about one inch. The locomotive has leading and trailing pony axles each of which has a radial movement, and one of them also has a lateral movement at the bolster. The fixed wheel base runs from the middle driving axle to the bolsters at the middle of the front truck. The truck design results in great freedom of adjustment and smooth running at curves. The cranks of the two motors are connected at each end of the motor by a yoke, which again is connected to the crank of the middle driving axle, but the bearing on this crank has a free vertical movement in the rod.

**The 1906 locomotives** have the driving axles, the pony axles, and the connections used for the 1904 locomotives. There are, however, three economical speeds, in place of two.

Motors are two, a 1200-h.p. and a 1500-h.p. At full speed only one motor is used and the locomotive is then rated at 1500 h. p. The relation of drawbar pull to speed is quoted as:

Two motors, cascade relation, 16 m.p.h., 14,500 pounds.
One 12-pole, 1200-h.p., 26 m.p.h., motor 12,100 pounds.
One 8-pole, 1500-h.p., 40 m.p.h., motor 12,100 pounds.
Two motors cannot be operated together at full speed.

DATA ON VALTELLINA RAILWAY LOCOMOTIVES.

| Locomotives ordered in | 1902 | 1904 | 1906. |
|---|---|---|---|
| Number ordered | two | two | two |
| Wheel arrangement | 0–4–4–0 | 2–6–2 | 2–6–2 |
| H. p. rating at each speed, in m. p. h. | 600 @ 18.3 mph. | 900@18.3 mph.<br>1200@37.0 mph. | ....@16 mph.<br>1200@25 mph.<br>1500@40 mph. |
| Full speed of motor, in r.p.m. | 128 | 225 | 225 |
| Pairs and diam. of drivers | four 55″ | three 59″ | three 59″ |
| Pairs and diam. of truck wheels. | none | two 33 | two 33 |
| Wheel base, total | 21′–8″ | 31′–10″ | 31′–2″ |
| Wheel base, rigid | 6′–7″ | 16′– 1″ | 15′–5″ |
| Weight, total tons | 52 | 68 | 69 |
| Weight on drivers, tons | 52 | 47 | 47 |
| Weight of motors, tons | 22 | 27.8 | 27.3 |

**References on Valtellina Locomotives, Italian State Railway.**

Wilson and Lydall: Vol. I, p. 347; Vol. II, p. 54, for duplex motors on 1904 loco.
Locomotive Tests: S. R. J., March 11, 1905; Aug. 5 and 25, 1905; Electrical World, Vol. 46, pp. 221 and 766, 1905; S. R. J., May 2 and 30, 1903, p. 663 and 788.
Hammer: Descriptive, A. I. E. E., Feb., 1901.
Waterman and Muralt: A. I. E. E., June, 1905; Nov., 1909.
Kando: Zeitschrift des Vereines deutscher Ingenieure, Jan., 1905 and Jan., 1909.
Valatin: Speed Control, S. R. J., Apr. 6, 1907, p. 575; weight factor, S. R. J., Jan. 4, 1908; Elektrische Kraftbetriebe and Bahnen, 1907, heft 6.

**GIOVI RAILWAY.**

**Giovi Railway,** an Italian State Railway, between Genoa, Piedmont, and Lombard, in 1909 installed electric power for the section between Genoa and Pontedecimo, 13 miles of double track.

The system is the 15-cycle, 3000-volt, three-phase.

Equipment was furnished by the Italian Westinghouse Company, and includes 20 locomotives for the Giovi Line; also 20 locomotives for the

Savonna-Çeva Line, about 12 miles west of Genoa; and 10 locomotives for the Mt. Cenis Tunnel.

The locomotives haul 1100 cars per day over the route and grades. The tonnage is twice that previously sent over this double track line. The service is stated to be the heaviest railroad freight traffic in the world hauled by electric locomotives.

Power station now contains two 6000-kv.a. steam turbines driving 15-cycle, 13,000-volt alternators, and a water rheostat which can automatically absorb a maximum of 4000 kw., if regenerated energy is not

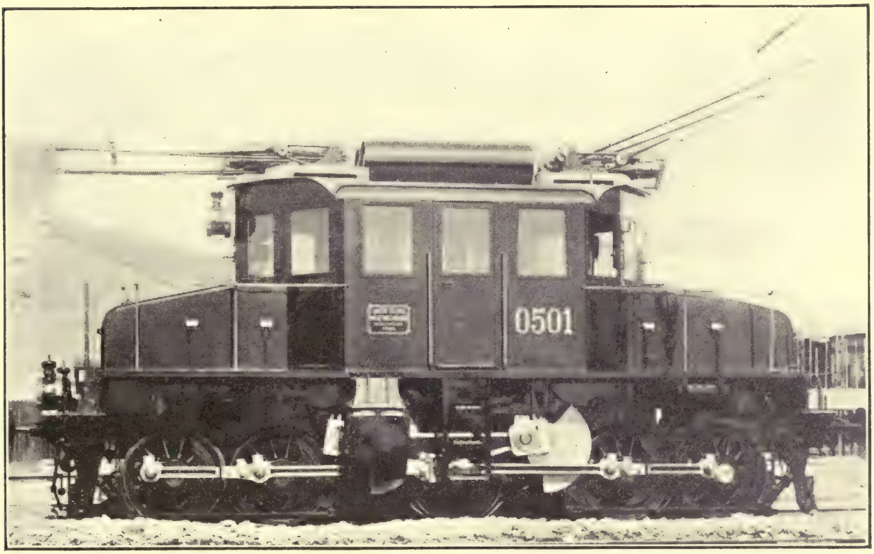


FIG. 118.—ITALIAN STATE RAILWAY LOCOMOTIVE. GIOVI LINE, 1909.

absorbed in useful work. There are four 3000-kw. step-down transformer substations along the 12.5-mile line, which reduce the voltage to 3000.

In general there are two 990-h.p., 225 r.p.m. motors per locomotive and two locomotives per train. The locomotives have 2 speeds—14.5 and 28 m.p.h. There are 5 coupled axles, and the drivers on the middle axle are without flanges. Front and rear axle have an 0.8-inch lateral movement. The two motors are placed over and between the axles nearest the middle of the locomotive and are crank-connected to the side rods, thru Scotch yokes.

**Specifications** for the 1909 Giovi locomotive follow:

Weight was not to exceed 67 tons; but the mechanical construction was to carry an additional 25 per cent. if required for adhesion for heavier trains than specified.

Trains to weigh 418 tons exclusive of the locomotives.

Locomotives to be used in pairs, one at each end of the train.

The road over which the locomotives were to be tested and used to be 12.5 miles long. The grades to average 2.70 per cent. for a distance of 6.5 miles, the ruling grade to be 3.50 per cent. for several miles, and a 2.90 per cent. g ade for 2.6 miles in one tunnel. Curves to have a 540-foot minimum radius.

Speed on the up-grades to be 28 m.p.h., and in regeneration on the down-grades to be 14 m.p.h. Acceleration to 28 m.p.h. to be carried out in 200 seconds, or at the rate of 0.14 m. p. h. p. s. Acceleration to 14 m.p.h. with one locomotive hauling 440 tons trailing load, on a 0.3 per cent. grade, and 540-foot radius curve, to be made 30 times per hour. Time for acceleration or for deceleration to be 2 minutes.

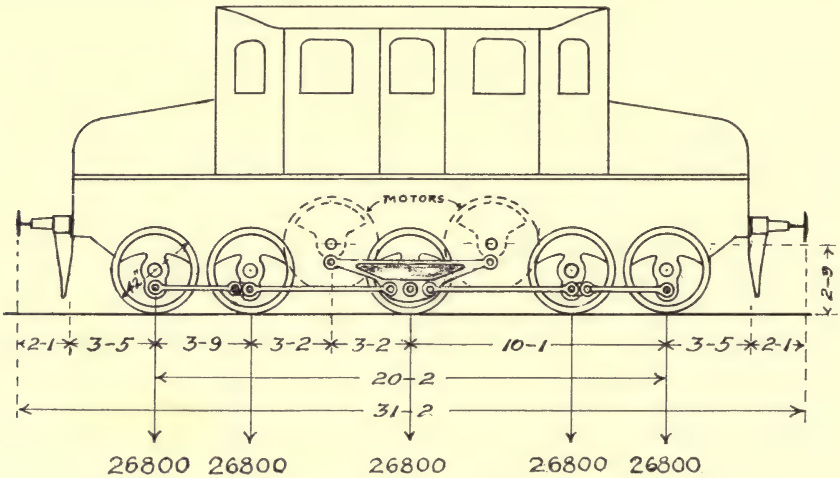


FIG. 119.—ITALIAN STATE RAILWAY LOCOMOTIVE. GIOVI LINE, 1909.
Giovi Line. 67-ton, 1980-h. p., 3-phase, 15-cycle, 3000–3000-volt motors for side-rod connection. Forced ventilation. Freight service.

Running time for 12.5 miles, at 28 m.p.h., to be 27 minutes; for the return 54 minutes; for the layover 59 minutes; round trip 140 minutes.

Temperature after 8.5 round trips or 20 hours' run with 418-tons trailing load, with forced draft, followed by one round trip without forced draft, was not to rise 75° C. by resistance (not by thermometer).

(Note: Power required on the 2.7 per cent. up-grade is $(418+67+67)\times(54+6)\times 28/375$ or 2475 h.p.; and on 3.5 per cent. up-grade is 3134 h.p. Power on the level, at full speed, is only 247 h.p.)

**Motors** have double frames, the outer of which is built into the main locomotive frame and has for its function only the maintenance of the air gap independent of changes in position of the locomotive frame members. The outer frame takes the thrust of the connecting rods. The motor is entirely spring mounted, on four spiral springs, two on each side of the motor axle boxes. The motors are slipped into place, in their outer frames, from below. A motor can be removed in two hours. Two motors weigh 27 tons. See Figure 50.

Motors are of the three-phase slip-ring, 8-pole type. Each is rated by the Italian Westinghouse engineers at nearly 1000 h. p. for 1 hour or 720 h. p. continuous on forced draft, based on 75° C. rise, determined by resistance measurements. Motors have partly closed slots for protection of windings in the rotor and stator. These slots are filled with a flexible insulating compound (which at times gets into the air gap).

**Control** is by means of the concatenated scheme. The rotor or secondary of the first motor delivers a very low voltage to the primary of the second motor. The secondary of the second motor is then connected to a compressed-air-controlled water rheostat, the gradual change in

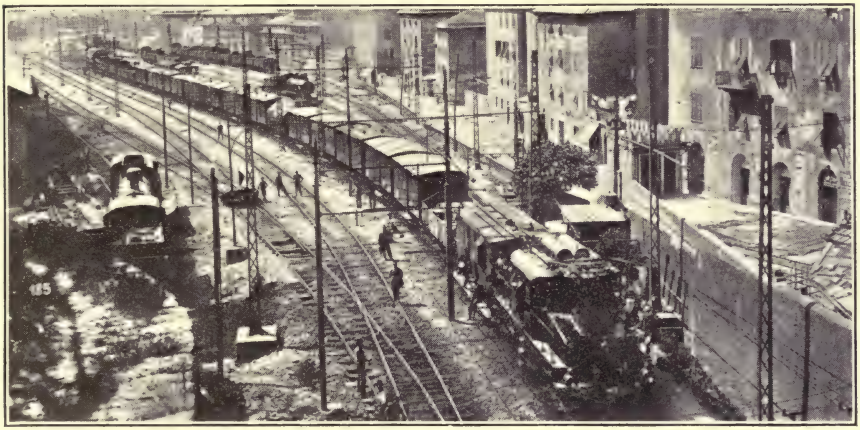

Fig. 120.—Italian State Railway.—Giovi Line.
Locomotives and 440-ton train on 3.5 per cent. grade.

which provides smooth acceleration. In order to change from parallel to concatenated connections or to reverse the direction of motor, a small 3000-volt, air-break switch is used to open the main circuit. Change is then made in the contact mechanism or connections, so that arcing does not occur at the controller contacts.

Multiple control is arranged, yet the current in any one motor is limited and locomotives with widely different wheel diameters and loads are used together. The pushing locomotive can then carry the larger load, as is frequently desirable. The current to a locomotive is limited by the addition of resistance, *automatically* inserted in the secondary of the motor by the action of induction regulators, relays, and compressed air which change the level of the water in the rheostats connected in the secondary circuits of the motors. Interlocks are arranged for compressed-air-operated switches, trolley, and rheostats. Bow trolleys with rolling contact were found to be suitable for the low speeds.

**References.**

Kando: Zeitschrift des Vereines deutscher Ingenieure, 1909, p. 1249, abstracted in E. W., Aug. 11, 1910. Sprecht: Elec. Journal, Dec., 1908.
London Electrical Engineering, Feb. 9, 1911.
E. R. J., April 8, 1911, p. 631.

## SWISS FEDERAL RAILWAY.

**Simplon Tunnel Line** from Brig in Switzerland to Iselle in Italy was completed and placed in service, with electric locomotive traction, in July, 1907. This 12.3-mile tunnel thru the Alps is the longest in the world. The grade is 0.7 per cent. thru one-half, and 0.2 per cent. thru the other half of the tunnel. The tunnel is very hot and moist, but it is ventilated by means of fans, the air having a velocity of 7 m. p. h.

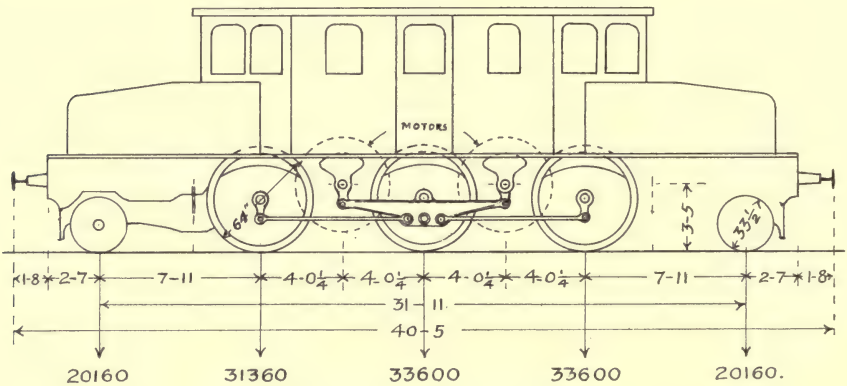


Fig. 121.—Swiss Federal Railway Locomotive, 1907.
Two used on Simplon Tunnel. 70-ton, 1100-h. p., 3-phase, 16-cycle, 3000–3000-volt motors for side-rod connection. Mixed service.

Water power is used for electric train haulage and comes from two central stations having a total capacity of 2700 h. p.

The system used is the 16-cycle, three-phase, with 3000 volts on the contact line, and also on the stator of the motors.

Each locomotive has two motors with cranks on the rotors which connect thru Scotch yokes to the driver side rods.

Two class 2–6–2 locomotives, built in 1907, each have two 550-h. p. *slip-ring* type motors, the control of which is by pole changing in the primary and resistance in the rotor or secondary. The speed is 21 or 43 miles per hour.

Two class 0-4-4-0 locomotives, built in 1909, each have two 850-h. p. *squirrel-cage* type motors, the control of which is by varying the voltage to the stator. The speed is 16, 21, 33, or 43 m. p. h. Leading and trailing

axles are surrounded by hollow axles which allow some lateral movement, and thus the use of pilot axles is avoided.

**Locomotive design** for the two 1909 locomotives shows a radical improvement. Experience had taught that four speeds were quite necessary. Collector-ring rotors were avoided on account of the limitations of shaft space and core width, and the awkwardness of this high-voltage, current-collecting device. Cascade control was not considered advantageous; on the contrary, it was cumbersome and complicated. The ideal three-phase motor was apparently not the bar-wound armature, with collector rings, and complicated connections.

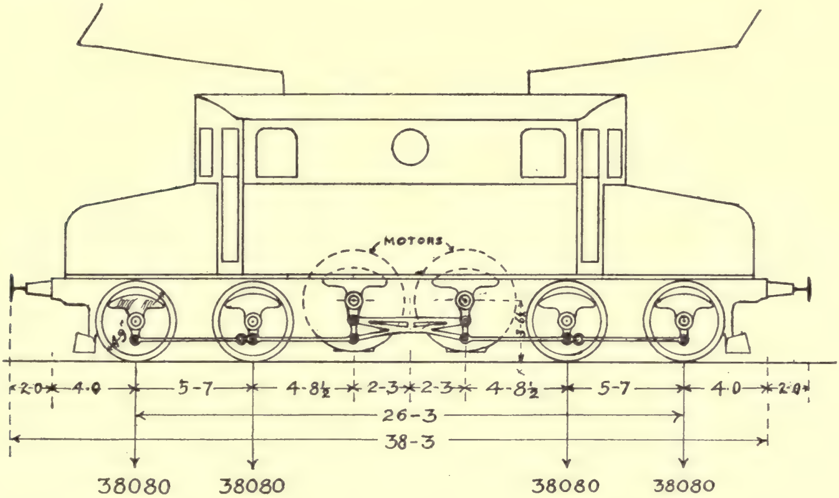


Fig. 122.—Swiss Federal Railway Locomotive, 1909.
Two used at Simplon Tunnel. 76-ton, 1700-h. p., 3-phase, 16-cycle, 3000–3000-volt motors for side-rod connection. Mixed service.

Squirrel-cage rotors were simple and rigid and had a minimum number of parts to get out of order. They were adopted for the 1909 locomotives. It is well known, however, that the squirrel-cage, low-resistance rotors have a low starting torque, but the windings were designed with 5 times the ordinary resistance to give sufficient starting torque.

**Specifications** for the latest or 1909 locomotives:

Drawbar pull to exceed 13,000 pounds when running at 40 to 50 m. p. h. and to exceed 5,500 pounds at a speed of 20 to 25 m. p. h., even should the normal voltage of 3000 drop to 2700. (Drawbar pull varies inversely as the square of the voltage.)

Locomotives to be capable of bringing a train of a total weight of 448 tons of 2000 pounds from rest to a speed of 20 m. p. h. in 55 seconds on the level; to bring a total weight of 280 tons from rest to a speed of 40 m. p. h. in 110 seconds; and to be capable of starting from rest with a total train weight of 280 tons on a 2 per cent. grade with certainty under all conditions.

Motors, starting resistance, and all electrical details to be proportioned to enable a train having a total weight of 448 tons to be accelerated from rest to 20 m. p. h. at least 30 consecutive times, at intervals of 2 minutes, on curves of not more than 600-feet radii, and with a gradient of not more than 0.3 per cent., without any part of the equipment sustaining injury from undue stress or overheating.

Motors after a continuous run of 10 hours at rated load, at either working speed, to have a temperature rise in any part of the motor, including the bearings, not to exceed 60° C.; and after a continuous run of 1 hour at 50 per cent. overload, or 200 seconds at 100 per cent. overload, the temperature rise was not to exceed 40° C.

**Motor torque and speed** are varied by changing from 16 to 12, 8, or 6 poles; and with 16 poles the drawbar pull is a maximum. The absolute torque is varied by regulating the voltage impressed upon the rotor. At the instant of starting the maximum energy is lost in heat in the rotor, while at full speed only a part of this loss

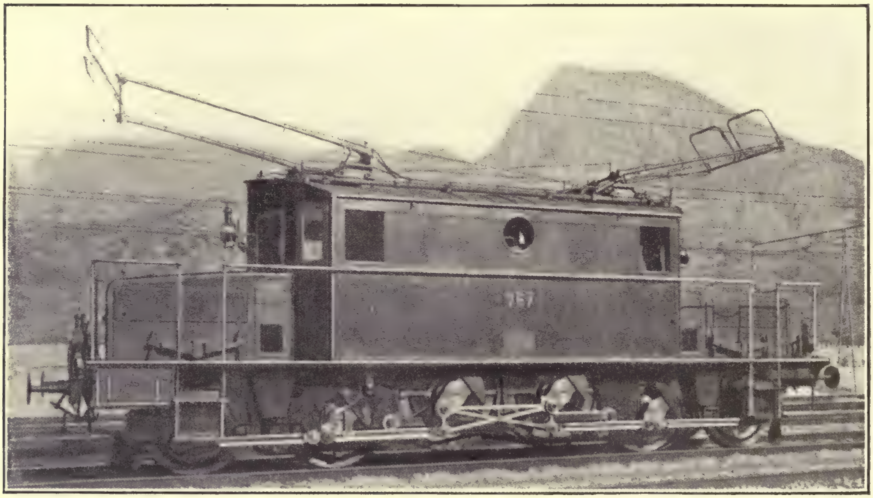

FIG. 123.—SWISS FEDERAL RAILWAY, SIMPLON TUNNEL LOCOMOTIVE, 1909.
Three-phase, 3000-volt, 16-cycle units. Brown, Boveri & Co.

exists. The starting torque is proportional to the loss in the rotor circuits, and can be obtained by using a large resistance and small current as in the collector ring rotor, or by using a large current and small resistance. The latter scheme is used. The rotor resistance is placed between the bars and the short-circuiting ring, and so arranged that temperatures of 250° C., or an increase in resistance of about 50 per cent., may be used under necessary circumstances. The loss in the stator winding is somewhat larger than in a collector ring type of motor. In other words efficiency is sacrificed for simplicity in the design and maintenance.

Parallel operation of different locomotives is not difficult. The maximum wear of the drivers, with electric braking, is 1.375 inches or about 3 per cent., and the squirrel-cage motors are designed for about 7 per cent. full-loaded slip.

Service reaches a maximum of 24 trains per day each way. It requires 700 h. p. more to run in the tunnel than in the open.

SIMPLON TUNNEL LOCOMOTIVE DATA.

| | | |
|---|---|---|
| Locomotives ordered in | 1907 | 1909 |
| Number ordered | 2 | 2 |
| Wheel order | 2–6–2 | 0–8–0 |
| Wt. of passenger cars | 326 | 392 |
| Wt. of freight cars | 448 | 730 |
| H. p. rating at 16.1 m. p. h. | | 1300 |
| 21.7 | 800 | 1100 |
| 32.2 | | 1300 |
| 43.5 | 1100 | 1700 |
| R. p. m. of motor, full speed | 240 | 320 |
| No. of axles, total | 5 | 4 |
| Pairs and diam. of drivers | 3–64.5″ | 4–49.0″ |
| Wheel base total | 31′–11″ | 26′–3″ |
| Wheel base rigid | 16′– 1″ | 5′–7″ |
| Wt. of electric motors, tons | 25.0 | 27.5 |
| Wt. of transformers | 0 | 6.6 |
| Wt. of lighting set and compressors | 8.0 | 5.0 |
| Wt. of mechanical parts | 37.0 | 37.0 |
| Wt. of locomotive, total | 69.0 | 76.0 |
| Wt. of locomotive on drivers | 50.0 | 76.0 |
| Wt. on each set of drivers | 16.6 | 19.1 |
| H. p. per ton, full speed | 15.9 | 22.4 |
| Ratio drawbar pull to weight on drivers in starting, per cent | 35.5 | 34.5 |

DRAWBAR PULL AT DRIVERS IN POUNDS.

Locomotive of 1907 rated 1100 h. p. at 44 m. p. h.

| | | | |
|---|---|---|---|
| Number of poles | 16 | 16 | 8 |
| Miles per hour | standstill | 21.73 | 43.47 |
| Pull on the level | 17,610 | 13,000 | 8,370 |
| Pull on 2.5 % grade | 17,610 | 9,480 | 5,080 |

Locomotive of 1909 rated 1700 h. p. at 44 m. p. h.

| | | | | | |
|---|---|---|---|---|---|
| Number of poles | 16 | 16 | 12 | 8 | 6 |
| Miles per hour | standstill | 16.46 | 21.73 | 32.91 | 43.47 |
| Pull on the level | 26, 400 | 24,800 | 21,800 | 16,320 | 13,250 |
| Pull on 2.5 % grade | 26, 400 | 21,200 | 18,050 | 12,350 | 9,470 |

**References on Simplon Tunnel Locomotives.**

S. R. J., Feb. 24, 1906; E. W., Oct. 27, 1906; Elec. Review, Nov. 13, Dec. 4, 1909.
Schweizerische Bauzeitung, Oct., 1909.
Zeitschrift des Vereines deutscher Ingenieure, Jan., 1909, p. 993.

**GREAT NORTHERN RAILWAY.**

**Great Northern Railway** has four 115-ton, 3-phase electric locomotives. They were ordered June, 1907, delivered February, 1909, and placed in full service during July, 1909.

The service is trunk-line freight and passenger-train haulage thru a tunnel in the Cascade mountains. The tunnel is 14,400 feet long and has a 1.7 per cent. grade. The route is 4 miles long; and the mileage is 6.

**Power** is derived from a water power plant on the Wenatchee River, 25 miles west of the tunnel. A 600-foot dam runs diagonally across the river. The water is led to the power house by means of a wood stave pipe 11,000 feet long and 8 feet 6 inches in diameter. The head is 140 feet. Generators consist of three 2000-kw., 3-phase, 25-cycle units.

**Transmission line** length is 30 miles. The voltage, which is 33,000, is stepped down at the tunnel to 6600 volts for use on the double trolley.

**Trucks** for the locomotives were designed for low speeds on grades, 15 m. p. h. They are of the articulated or hinged type, with 4 drivers on


Fig. 124.—Great Northern Railway Locomotive, 1909.
Four used at Cascade Tunnel. 116-tons, 1700-h. p., 3-phase units. 25-cycle, 6000-volt line. Four 500-volt geared motors.

each half of the running gear, and there are no guiding wheels. The hinged sections are designed to guide each other on curves. Trucks are equalized to distribute the stresses over the springs and to eliminate twisting stresses in the truck frame and running gear. The truck design is described on page 319. The rigid wheel base is 11 feet, and the total wheel base 31 feet 9 inches. Drivers are 60-inch.

**The framing** is made of annealed steel castings. Sides are trussed, and end frames and bolsters are steel castings of the box girder type designed for buffing stresses of 500,000 pounds. Bolsters are hollow and form part of the air duct for the motor ventilation. The cab is carried on center pins on each bolster. One of the center pins provides for a longitudinal variation in the distance between truck centers on curves.

**Transformers** on each locomotive are two 400-kw., three-phase.

They reduce the voltage from 6000 to 500. These transformers and the motors are cooled by a motor-driven fan which furnishes 9400 cubic feet of air per minute at 2-ounce pressure.

**Motors** are four 3-phase, 25-cycle, 120-ampere, 8-pole, 500-volt, of the slip-ring type units, rated 475 h.p. for 1 hour when supplied with 1500 cubic feet of air per minute at 2-ounce pressure. The diameter of the armature is 35 3/4 inches, and the width is 16 1/4 inches. Gear ratio is 4.26, and double gearing is used between the 358 r. p. m. rotor and the axle. Maximum power factor is 86. Air-gap is 1/8 inch.

Horse power rating per motor is as follows:

| Time in hours. | Cooling method. | Air c.f.m. | Volts to motor. | Power h.p. | Note No. |
|---|---|---|---|---|---|
| One hour, 75°.... | Natural..... | 0 | 500 | 425 | 1 |
| | | 0 | 625 | ........ | ........ |
| One hour, 75°.... | Forced...... | 1500 | 500 | 475 | 1 |
| | | | 625 | 550 | 2 |
| Continuous, 75°.. | Natural..... | 0 | 500 | 250 | 3 |
| Continuous, 75°.. | Forced...... | 1500 | 500 | 375 | 1 |
| | | | 625 | 400 | 2 |
| Continuous, 40°.. | Forced...... | 1500 | 500 | 260 | 2 |

Tractive effort at 375 h.p. is 9350 pounds; at 475 h.p. is 11,875 pounds.

*Note* 1. C. T. Hutchinson data to A. I. E. E., Nov., 1909, p. 1285.

*Note* 2. E. F. W. Alexanderson data to A. I. E. E., Nov., 1909, p. 1342.

*Note* 3. G. E. bulletin 4851, June, 1911.

Transformers have a 3-hour rating of 400 kv.a. with forced draft.

**Motor control** is by means of a variation of resistance in the rotor circuit. Two motors are used in first starting and four while running.

**Weight** of locomotive in pounds is:

| | |
|---|---|
| Two trucks | 81,500 |
| One cab | 30,000 |
| Four motors, 425-h. p. each | 59,800 |
| Two transformers, 400-kw. each | 20,800 |
| Compressors and blowers | 7,100 |
| Control equipment | 13,400 |
| Miscellaneous | 17,400 |
| Total weight | 230,000 |

Weight per axle 57,500 pounds; dead weight per axle, 18,500 pounds.

**Service** consists of the haulage of about 3 passenger and 3 freight trains each way per day. Trailing tons for freight trains exclusive of 3 electric locomotives are 1750; and for passenger trains exclusive of 2 electric locomotives are 775 tons. Annual locomotive mileage is 50,000.

This was the first three-phase locomotive equipment in America. The installation is radically different from the installations made by Ganz, Brown-Boveri, Westinghouse, and Oerlikon in the following:

1. Trolley contacts are used in place of pantographs or bows, with cylinders or sliders. Trolley wheels are held to be a nuisance. The changing of 6 trolleys at the end of each short run, and in the dark at night, is a nuisance. A simple, wide pantograph could be substituted for the contact wheels. Catenary construction, parallel to the trolleys, was not used to support the trolley in the switch yards. The overhead pan switch design used is unsatisfactory and is a source of annoyance and danger, even at the slow speed. See Figures 175 and 176.

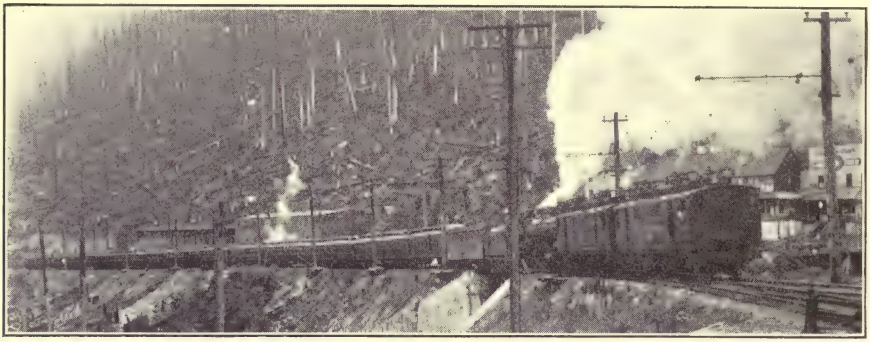

FIG. 125.—GREAT NORTHERN LOCOMOTIVE AND TRAIN, 1909.
Two electric locomotives hauling an ordinary 11-coach train and steam locomotive.

2. Twenty-five cycles have been tried. If 15 cycles had been adopted, two locomotives per freight train might have been used in place of three.

3. Two transformers are located on each locomotive, in place of in a substation at the side of the road.

4. The locomotive has only one running speed.

5. Slip-ring motors with brush contacts are used in place of simple high-resistance, squirrel-cage motors.

6. Geared motors are used. The length along the shaft, available for collector rings and for the gear teeth, is much restricted.

7. Motors are hung on an axle and on a cross bar, as in trolley cars. The center line of the motors is below the center line of the axle. The dead weight per axle is 18,500 pounds. The track repairs are high.

8. The electric system was laid out for long-distance mountain-grade railroad service. The locomotives cannot be used for such service without a radical change in the design.

**Service with steam locomotives** in the Cascade tunnel was described by Hutchinson to A. I. E. E., November, 1909:

"Trains east bound from the Pacific coast were from 1400 to 1500 tons trailing load with two Mallet compound engines. At the west end of the tunnel, at the foot of the grade, all trains were stopped, fires were hauled and cleaned, the engine took on a special high-grade coal, new fires were built, the engines remained in the yard for an

hour or more, coking these fires in order to get rid of superfluous gas. The train was divided so that two Mallets took 1,000 tons (up the 1.7 per cent. grade). When weather conditions were bad it was almost impossible to get trains thru the tunnel. Sometimes it was necessary to wait 2 or 3 hours after the passage of a train before it was safe to send a second train thru. Frequently the steam pressure of the rear Mallet would fall from 200 pounds to 70 pounds or less, owing to the impossibility of maintaining fires on account of the exhausted condition of the air in the tunnel."

**Operating results with electric traction** have been reported as both favorable and unfavorable. The system is new and time will be required to fit the electric locomotive to the service on this steam road.

The railway company, having found that electric locomotives could haul much more than that for which they are guaranteed, proceeded to overload the motors, and the tonnage in each train, thereby effecting certain economies at the expense of the electric service.

In going down grades the motors automatically reverse their function and return power to the line, and thus brake the train without the application of mechanical brakes. The air brakes are held in reserve.

"With electric locomotives the operation on a heavy grade becomes as simple as on a level; the enginemen and trainmen feel much greater confidence in the electric locomotives and consequently the mountain division ceases to be a terror to them." Hutchinson.

### References on Great Northern Railway Locomotives.

General Electric bulletin 4537, Sept., 1907; G. E. Review, Aug. and Sept., 1910.
E. R. J., Dec. 28, 1907; Oct. 31, 1908; Nov. 20, 1909.
Elec. World, Oct. 31, 1908.
R. R. Age Gazette, Jan. 15, 1909; Dec. 3 and 24, 1909.
Hutchinson: Paper and discussion, proceedings of A. I. E. E., Nov., 1909.
Slichter: Design of Controllers, A. I. E. E., Nov. 1909, p. 1338.

### References to Detailed Drawings of Three-phase Locomotives.

| Name of locomotive. | Maker. | Location. | References. |
|---|---|---|---|
| Italian State | West | Giovi Line | Zeitschrift, 1909, p. 12. |
| Swiss Federal | Brown | Simplon, 1907 | Zeitschrift, 1909, p. 3. |
| Swiss Federal | Brown | Simplon, 1909 | A.I.E.E., July, 1910, Eaton & Storer. |
| Italian State | Ganz | Valtellina | S.R.J., April 6, 1907, p. 579. |
| Great Northern | G.E. | Cascade Tunnel. | E.R.J., Nov. 20, 1909. |
| | | | G.E. Bulletin 4537, 1907, p. 13. |

## CHAPTER X.

# TECHNICAL DESCRIPTION OF SINGLE-PHASE LOCOMOTIVES.

### Outline.

LIST OF ELECTRIC LOCOMOTIVES, SINGLE-PHASE 25-CYCLE.

| Name of railroad. | No. of loco. | Name of builder. | No. of motors. | Total h.p. | Wt. tons. | Drivers. | | Gear ratio. | Trolley voltage. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Pr. | Diam. | | |
| Westinghouse Inter-works. | 2 | West.... | 3 | 675 | 63 | 3 | 60″ | 5.28 | 6,600 |
| Pennsylvania experi-mental. | 1 | West.... | 2 | 920 | 70 | 2 | 72 | Zero | 11,000 |
| New York, New Haven & Hartford. | 35 | West.... | 4 | 960 | 96 | 4 | 62 | Zero | 11,000 |
| | 6 | West.... | 4 | 960 | 102 | 4 | 62 | Zero | |
| | 1 | West.... | 4 | 1260 | 136 | 4 | 63 | 2.32 | |
| | 1 | West.... | 2 | 1350 | 135 | 4 | 57 | Crank | |
| | 1 | West.... | 8 | 1396 | 116 | 4 | ....... | ....... | |
| | 15 | West.... | 4 | 600 | 80 | 4 | 63 | Gear | |
| Windsor, Essex & L. S. | 1 | West.... | 4 | 400 | 35 | 4 | 36 | ....... | 6,600 |
| Spokane & Inland Empire. | 6 | West.... | 4 | 500 | 50 | 4 | 36 | 4.24 | 6,600 |
| | 8 | West.... | 4 | 680 | 72 | 4 | 50 | 5.65 | 6,600 |
| Grand Trunk Ry., Sarnia Tunnel..... | 6 | West.... | 3 | 675 | 66 | 3 | 62 | 5.31 | 3,300 |
| Rock Island Southern. | 1 | West.... | 4 | 500 | 60 | 4 | 42 | ....... | 11,000 |
| Boston & Maine..... | 3 | West.... | 4 | 1340 | 130 | 4 | 63 | 4.14 | 11,000 |
| | 2 | West.... | 4 | 1340 | 130 | 4 | 63 | 2.32 | |
| Illinois Traction (repulsion motors) | 1 | G.E..... | 4 | 600 | 50 | 4 | 44 | 4.95 | 3,300 |
| Swedish State: Stockholm Div.... | 1 | West.... | 2 | 300 | 28 | 2 | 42″ | 3.88 | 18,000 |
| | 1 | West.... | 4 | 460 | 40 | 4 | 44 | 5.27 | |
| | 1 | Siemens . | 3 | 330 | 51 | 3 | 43 | 5.00 | |
| Thamshavn-Lokken, Norway. | 3 | West.... | 4 | 160 | 22 | 4 | ....... | ....... | 11,000 |
| | 3 | Siemens . | 4 | 160 | ....... | .... | ....... | ....... | |
| Tergnier-Anizy, France. | 3 | West... | 2 | 80 | ....... | .... | ....... | ....... | 3,300 |
| Prussian State: Oranienburg....... | 1 | A.E.G... | 3 | 1050 | 65 | 4 | 55 | 4.15 | 6,000 |
| | 1 | A.E.G... | 2 | 600 | ....... | .... | ....... | 2.36 | |
| | 1 | Siemens . | 3 | 1050 | 66 | 3 | ....... | Geared | |
| St. Polten-Mariazell... | 17 | Siemens . | 2 | 500 | 50 | 6 | 33 | 2.90 | 6,000 |
| Frieburg............ | 1 | Oerlikon. | 4 | 600 | ....... | .... | ....... | 4.00 | |
| Albtal Ry.: Karlsruhe-Herrenalb | 4 | A.E.G... | 4 | 340 | 35 | 4 | 36 | 6.10 | 8,000 |
| Brembana Valley, Bergamo-Bianco .. | 5 | West.... | 4 | 300 | ....... | .... | ....... | 4.66 | 6,000 |
| Rome-Castellana .. | 3 | West.... | 4 | 160 | ....... | .... | ....... | ....... | 6,600 |
| | 4 | Siemens. | 4 | 160 | ....... | .... | ....... | ....... | |
| Naples-Piedemonte .. | 2 | A.E.G... | 4 | 320 | ....... | .... | ....... | ....... | 11,000 |

## LIST OF ELECTRIC LOCOMOTIVES, SINGLE-PHASE, 15-CYCLE.

| Name of railroad. | No. of loco. | Name of Builder. | No. of Motors. | Total h.p. | Wt. tons. | Drivers. pair. | Drivers. diam. | Gear ratio. | Trolley voltage. |
|---|---|---|---|---|---|---|---|---|---|
| Pennsylvania 10003 experimental. | 1 | West. . . . . | 2 | 920 | 76 | 4 | 72″ | Gear-less. | 11,000 |
| Visalia Electric. . . . . | 1 | West. . . . . | 4 | 500 | 47 | 4 | 36 | 3.89 | 3,300 |
| General Electric. . . . | 1 | Gen. Elec. | 2 | 800 | 125 | 3 | 49 | Crank | 11,000 |
| Shawinigan Falls. . . . | 1 | Gen. Elec. | 4 | 600 | 50 | 4 | 36 | 4.95 | 6,600 |
| Swiss Federal: | | | | | | | | | |
| Seebach-Wettingen experimental. | 1 | Leonard . . | 4 | 400 | 52 | 4 | . . . . . . . | 3.50 | 15,000 |
| | 1 | Oerlikon . . | 2 | 500 | 45 | 4 | 40 | 3.08 | |
| | 1 | Siemens . . | 6 | 1350 | 83 | 3 | . . . . . . . | 3.75 | |
| Bavarian State: Murnau-Oberammergau. | 2 | Siemens . . | 2 | 350 | . . . . . | 2 | . . . . . . . | 5.00 | 5,500 |
| Prussian State: Magdeburg-Leipzig. | 1 | A.E.G. . . | 1 | 1900 | . . . . . . | . . . . . . | . . . . . . . | Crank | 10,000 |
| | 1 | A.E.G. . . . | 1 | 1000 | 77 | 4 | 63 | Crank | |
| | 1 | A.E.G. . . . | 1 | 800 | 64 | 4 | 41 | Crank | |
| | 2 | Brown. . . . | 2 | 1600 | . . . . . . | 4 | 69 | Crank | |
| | 1 | Bergmann. | 1 | 1500 | . . . . . . | . . . . . . | . . . . . . . | Crank | |
| | 1 | Oerlikon. . | 1 | 800 | | | | | |
| | 1 | Siemens . . | 1 | 1100 | | | | | |
| | 1 | Siemens . . | 1 | 1800 | | | | | |
| | 1 | Siemens . . | 2 | 2500 | | | | | |
| Baden State: | | | | | | | | | |
| Wiesental (Basel-Zell). | 10 | Siemens . . | 2 | 1050 | 71 | 3 | 47 | 4.15 | 10,000 |
| | 1 | A.E.G. . . . | 2 | 1130 | | | | | |
| Bernese Alps. . . . . . . | 1 | Oerlikon. . | 2 | 2000 | 97 | 6 | 54 | C. & G. | 15,000 |
| | 1 | A.E.G. . . . | 2 | 1600 | 103 | 4 | 50 | Crank | |
| Budapest-Waitzen . . | 4 | Siemens . . | 4 | 480 | . . . . . . | . . . . . . | . . . . . . . | . . . . . . . | 10,000 |
| French Southern. . . . | 6 | West. . . . . | 2 | 1600 | 89 | 3 | . . . . . . . | C. & G. | 12,000 |
| | 1 | A.E.G. . . . | 2 | 1600 | 94 | 3 | . . . . . . . | Crank | |
| | 1 | Brown. . . . | 2 | 1600 | . . . . . . | . . . . . . | . . . . . . . | Crank | |
| Swedish State: Kiruna-Riksgransen. | 13 | Siemens . . | 2 | 2000 | . . . . . . | . . . . . . | . . . . . . . | Crank | 15,000 |
| | 2 | Siemens . . | 1 | 1000 | . . . . . . | . . . . . . | . . . . . . . | Crank | |
| Mittenwald, Austria. | 6 | A.E.G. . . . | 1 | 800 | 64 | 4 | 41 | Crank | 10,000 |
| Rjukon, Norway. . . | 3 | A.E.G. . . . | 4 | 500 | 44 | 4 | 39 | Gear | 10,000 |
| | 2 | A.E.G. . . . | 2 | 250 | . . . . . . | . . . . . . | . . . . . . . | Gear | |
| Vienna-Pressburg. . . | 3 | A.E.G. . . . | 3 | 800 | . . . . . . | . . . . . . | . . . . . . . | Gear | 10,000 |
| | 2 | A.E.G. . . . | 5 | 600 | . . . . . | . . . . . . | . . . . . . . | Gear | |
| Rhatische Mtn . . . . . | 3 | . . . . . . . . . | . . . . . . . . | 600 | . . . . . . | . . . . . . | . . . . . . . | . . . . . . . | 10,000 |
| | 8 | . . . . . . . . . | . . . . . . . . | 300 | | | | | |

**Literature.**

References on Detailed Drawings of Single-phase Locomotives, 399

# CHAPTER X.

## DESCRIPTION OF SINGLE-PHASE LOCOMOTIVES.

### IN GENERAL.

The technical descriptions which follow are for the most important and typical installations.

### WESTINGHOUSE INTERWORKS RAILWAY

**Westinghouse Interworks Railway,** at East Pittsburg, Pa., used the first single-phase railway locomotive in America. It was built in 1905 for freight switching work, at 10 miles per hour.

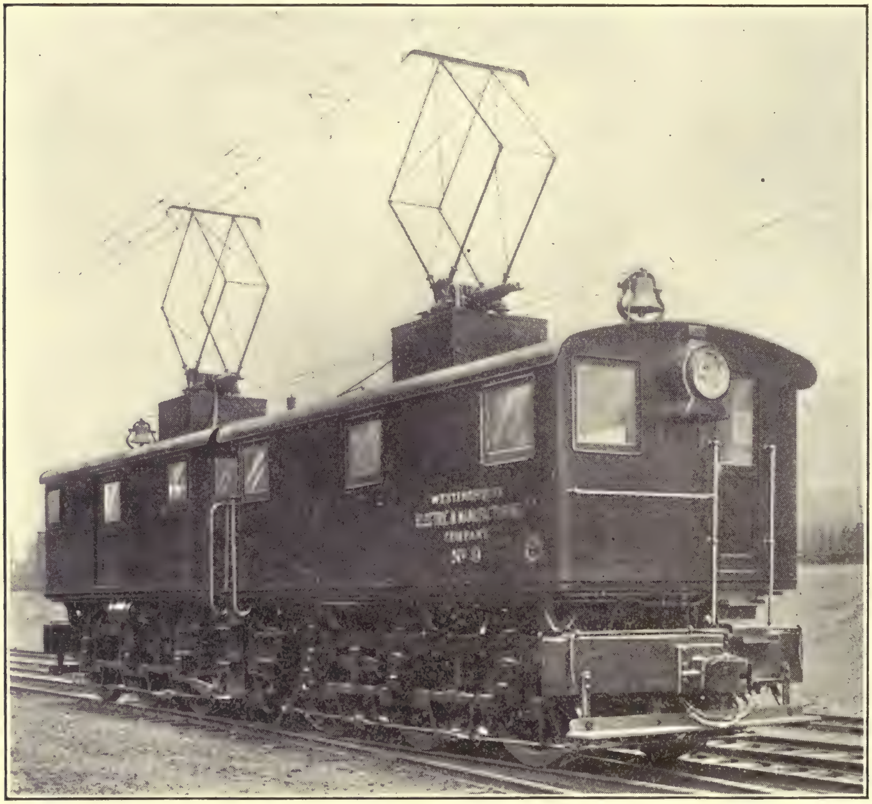

FIG. 126.—FIRST SINGLE-PHASE LOCOMOTIVE IN AMERICA, 1905.

Two locomotive units, Nos. 8 and 9, were used in pairs. Each weighed 63 tons, had 3 motors, 3 pairs of 60-inch drivers, and three 8-inch axles, spaced on 6-foot 4-inch centers, on one truck.

Motors were a single-phase, 25-cycle, 8-pole, geared type, with forced

ventilation. The capacity of each was 225 h. p. A 5.28 gear ratio was used. The 6600 volts on the trolley were reduced by a transformer to from 140 to 325 volts for the motors. The motor armatures were quill-supported on the axle, and the motor frames were spring-suspended from the locomotive body. Efficiency and power factor were .866 and .865 respectively at normal load, and .865 and .955 at half load.

Tests at the yards showed a normal drawbar pull of 48,500 pounds, and from 65,000 to 97,000 with sand, before slipping occurred, or up to

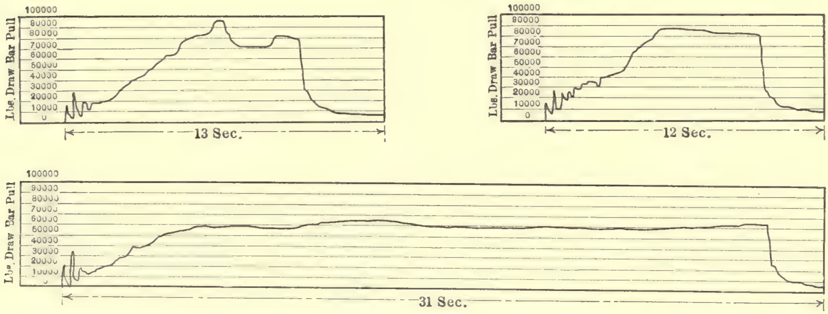


Fig. 127.—Test Curves Showing Drawbar Pull Exerted by Westinghouse Single-phase Electric Locomotive.

Equipped with six 225-h. p., single-phase railway motors, having a 5.3 gear ratio. Diameter of drivers, 60 inches. Weight of 50-car train, 1162 tons; weight of locomotive, 126 tons; total weight, 1288 tons. Brakes set on the four rear cars.

38 per cent. of the weight on drivers. Dynamometer records were made while hauling a train with a total weight of 1288 tons. Other tests showed an acceleration rate, during the first 40 seconds, of 0.25 m. p. h. p. s., while hauling an 818-ton train. See accompanying curves.

### References.

E.W., May 20, 1905, p. 925; drawings, June 3, 1905, p. 1045; S. R. J., May 20, 1905, and June 3, 1905, pp. 923 and 999; Electric Journal, Vol. II, July, 1905, pp. 359 and 764.

### PENNSYLVANIA RAILROAD, SINGLE-PHASE.

**Pennsylvania Railroad Company** had the Westinghouse Company build a locomotive known as 10003, in 1909, for use in experimental work on Long Island, to determine the mechanical and electrical requirements for Pennsylvania Railroad locomotives at its New York terminal.

Specifications called for a passenger locomotive of the Atlantic type, a maximum drawbar pull of 24,000 pounds, a weight of 70 tons, and a rating of about 1000 h.p., for use on a single-phase, 11,000-volt line, to haul a 400-ton trailing load at 60 m. p. h. on level track. It was also to be

suitable for speeds up to 80 m. p. h., and the haulage of trains on 2 per cent. grades in terminal service.

Weight of the locomotive on four 72-inch drivers is 50 tons, and on four 36-inch pony truck wheels is 20 tons.

Frames are those of an Atlantic type locomotive, with cast-steel members, sills and cross girders. Frames are placed outside of the wheels. Truck-wheel base for the drivers is 7 feet 6 inches; for the pony truck 6 feet 2 inches; total for each half locomotive is 20 feet 7 inches; total for the two-part, articulated locomotive 56 feet 2 inches.

**Motors** are single-phase, 15-cycle, 275-volt, gearless types, provided with forced ventilation. The 1-hour rating is 460 h. p. and the continuous rating with forced ventilation is 378 h. p. Each armature weighs 9350 pounds. The motor weight, about 19,500 pounds, is spring-supported. The armatures are flexibly connected to the drivers in the same way as the passenger locomotives of the New York, New Haven & Hartford, to be described. No provision is made for direct-current operation. A transformer which reduces the trolley voltage of 11,000 volts is carried under the floor, but over the pony trucks, where it is entirely out of the way. A 25-cycle locomotive built for the same work, speed, and grades would have required three motors of approximately the same dimensions and would have increased the weight of the locomotive from 70 tons to 92 tons, and the cost probably 30 per cent. The transformers alone would have cost less, but the control equipment would have cost enough more to counterbalance this item.

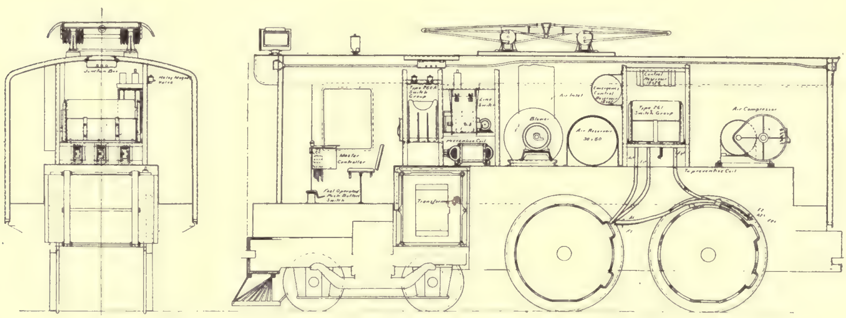

FIG. 128.—PENNSYLVANIA RAILROAD. EXPERIMENTAL LOCOMOTIVE, 1909.
Two single-phase 460-h. p., gearless, quill-mounted motors. Atlantic type locomotive, No. 10,003.

Tests showed that the locomotive could carry 100 per cent. overload in current for several minutes at a time, when hauling a train with the brakes set; and there was practically no sparking at the commutator.

Tests were also made to compare several types of electric locomotives, including the Pennsylvania experimental direct-current locomotives already described, and steam locomotives of many types, to determine

the best electrical and mechanical constants. Tests on track pounding, nosing, safety in high-speed service, and on overhead construction were conducted on a grand scale. These tests furnished the basis for the adoption of the present 157-ton Pennsylvania electric locomotives, used for the New York terminal service.

**References.**

S. R. J., June 29, July 20, Oct. 26, 1907.
Storer: A. I. E. E., June 1907, pages 1390 and 1405.
Gibbs: E. R. J., June 3, 1911, p. 960.


Fig. 129.—Pennsylvania Railroad. Experimental Locomotive and Train, 1909. Single-phase gearless motors.

## SPOKANE & INLAND EMPIRE.

**Spokane & Inland Empire Railroad** ordered from Westinghouse Company six 500-h.p. locomotives and eight 680 h.p. locomotives in 1906, 1907, and 1909, for ordinary freight service between Spokane and Colfax, or Moscow, points 80 and 90 miles apart. The single-phase, 6600-volt, 25-cycle system is used.

The 500-h.p. locomotives, which weigh 52 tons on 4 pairs of 38-inch drivers, have 4 motors with a 4.25 gear ratio.

The 680-h.p. locomotives, which weigh 72 tons on 4 pairs of 50-inch drivers, have 4 motors with a 4.65 gear ratio. These locomotives are rated on a continuous tractive effort of 16,000 pounds and are guaranteed to be able to run up 2 per cent. grades indefinitely without overheating. A tractive effort of 36,000 pounds is used in emergencies.

Motors were at first artificially cooled by fans on the motor shaft; but, with the series motor characteristics, the cooling effect decreased as the load increased. Forced ventilation from independent motors is used.

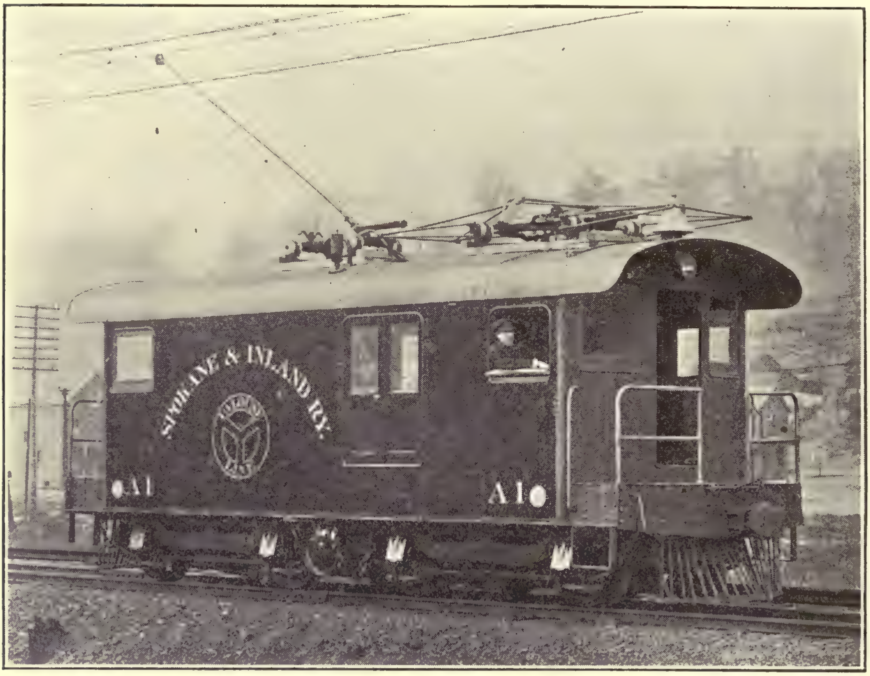


FIG. 130.—SPOKANE AND INLAND EMPIRE RAILROAD LACOMOTIVE, 1906.


FIG. 131.—SPOKANE AND INLAND EMPIRE RAILROAD LOCOMOTIVE, 1909.


FIG. 132.—SPOKANE AND INLAND EMPIRE RAILROAD FREIGHT LOCOMOTIVE, 1910.
One of eight, 72-ton, 680-h. p., geared, single-phase units.

PERFORMANCE CHARACTERISTICS OF THE 680-H. P. LOCOMOTIVE.

| Current amperes. | Power factor. | Speed m.p.h. | Tractive effort, lb. | Power h.p. | Notes or conditions. |
|---|---|---|---|---|---|
| 4800 | .805 | 8.0 | 39,600 | 845 | Gear ratio 4.65. |
| 4000 | .835 | 9.6 | 30,000 | 770 | Drivers 50-inch. |
| 3600 | .840 | 10.6 | 25,500 | 720 | Voltage 6600/220. |
| 3320 | .860 | 11.6 | 22,200 | 680 | One-hour rating, 680 h.p. |
| 2840 | .880 | 13.5 | 17,200 | 616 | ...................... |
| 2560 | .895 | 15.0 | 14,400 | 560 | Continuous rating, 560. |
| 2000 | .927 | 19.0 | 8,800 | 445 | ...................... |
| 1400 | .960 | 27.0 | 4,200 | 300 | Motors, 4 No. 151. |

## NEW YORK, NEW HAVEN & HARTFORD.

**New York, New Haven & Hartford Railroad Company** has used 35 single-phase locomotives, built by the Westinghouse Company, since July, 1907 and 41 since 1908, for passenger service between the Grand Central Station at New York City and Stamford, Connecticut, on 34 miles of 4-track road. The company has running rights over the tracks of the New York Central from the New York City terminal to

Woodlawn, a distance of about 12 miles from the terminal, and is compelled to use the 660-volt, direct-current system in this section. Beyond, the 11,000-volt, single-phase, 25-cycle system is used.

**Specifications** required that each passenger locomotive should be able to handle a 200-ton train (which was formerly the average weight of 75 per cent. of the local trains) in the most severe schedule, on a time-table corresponding to that of the local express, making 40 second stops every 2.2 miles, and a schedule speed of over 26 m. p. h. The locomotive was

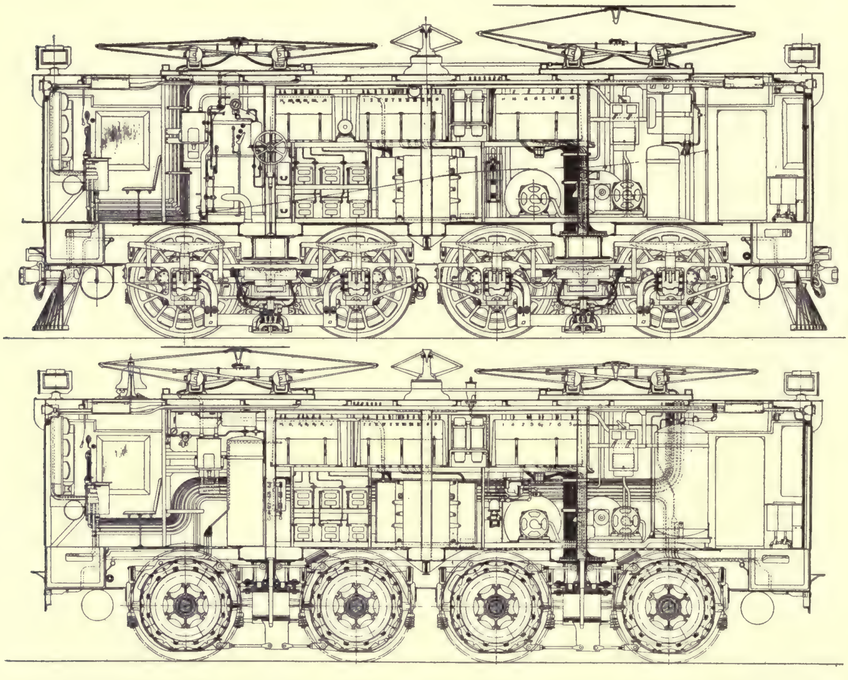

Fig. 133.—New York, New Haven and Hartford. Drawing for Passenger Locomotive, 1907.

to haul this train at 65 to 70 m. p. h., and 250-ton thru express trains at 60 m. p. h. A 300- to 500-ton train was to be operated at high speeds by coupling two locomotives and operating them on the multiple-unit plan.

**Guarantees** on the locomotive were that it would have sufficient capacity to handle a 200-ton trailing load in continuous local service; a 250-ton trailing load in local service as far as Port Chester, 25.6 miles; and a 300-ton trailing load in express service, to New Rochelle, 16.6 miles. The New Haven locomotives were designed, primarily for express service. See proceedings of A. I. E. E., Dec., 1908, p. 1693.

**In service,** one New Haven locomotive handles easily a load of 300 tons, and 360 tons have been hauled when necessary. One locomotive

ordinarily handles a 6-car train, making all the stops from Grand Central Station to either New Rochelle or to Stamford and two locomotives ordinarily handle a 6- to 10-car train making all stops. Local trains of 7 to 8 cars between Woodlawn and New Rochelle make stops every 1.4 miles. Express trains of 9 to 12 cars hauled by two locomotives make 12 stops between Woodlawn and Stamford, 33.4 miles. Express trains do not use the average power required by local trains with their local service stops. Double heading is required on from 15 to 25 per cent. of the New Haven trains.

**Locomotive frames,** of steel, 36 feet long, were built by Baldwin. The longitudinal members of the frame are deep plate girders reinforced at the top by channels and at the bottom by heavy angles and plates.

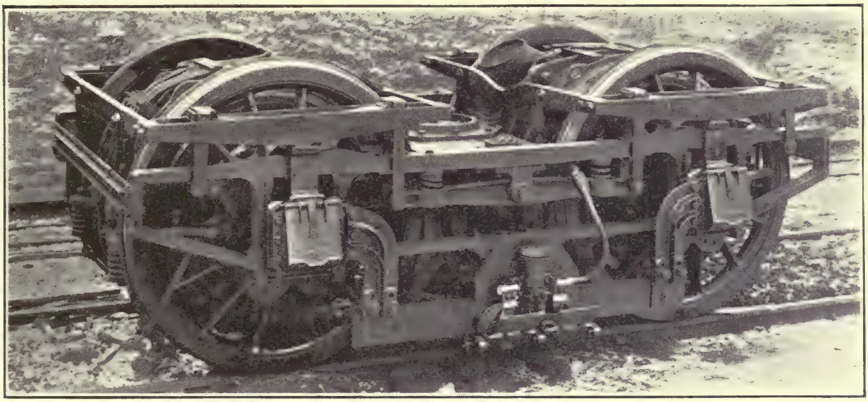

FIG. 134.—NEW YORK, NEW HAVEN AND HARTFORD. PASSENGER MOTOR TRUCK AND GEARLESS MOTOR.

The transoms are riveted to the frames, and braced by gusset plates riveted to the bottom flanges of two sets of channels. The drawbar effort is transmitted thru the bolsters, center pins, and the side frames to deep box girders joining the end frames.

**Two trucks** of the swivel pattern are mounted on 62-inch drivers. The truck centers are 14 feet 6 inches. The truck wheel base is 8 feet. Center bearings are 18 inches in diameter. Weights on the journals are carried by semi-elliptic springs.

**Pony wheels** added to each locomotive in 1908 improved the riding qualities and the safety at high speeds. The total wheel base was increased 100 inches. The pony truck wheels are 33 inches in diameter and are carried on an extension frame rigidly bolted to the main truck frame, without a bolster. To provide radial movement of the pony truck wheels, a bevel brass wedge is placed over the journal box of the pony truck which allows journal box, axle, and wheels to move laterally

between the pedestal jaws of the frames; but in so doing, they are met by the resistance in a bearing plate above the journal box. When the pony truck wheels move sidewise they lift, thru the bevel-bearing wedge, all the weight carried by the equalizer bars, and this tends to restore the pony truck wheels to their normal central position.

**Weight** of the first locomotive built was 89 tons, altho the estimated weight was 76 tons. The additional weight put into the locomotive, including 5 tons of third-rail and direct-current apparatus, mechanical

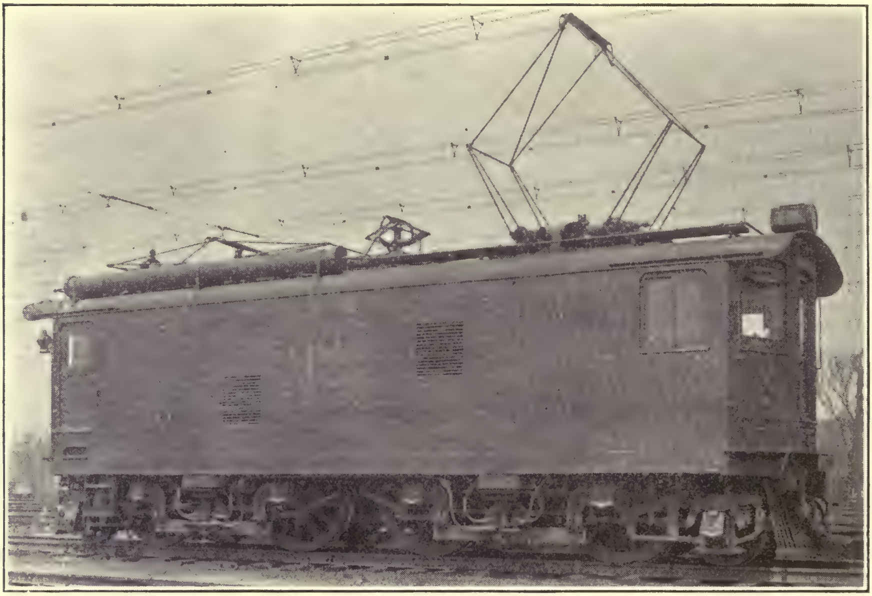

Fig. 135.—New York, New Haven and Hartford Passenger Locomotive, 1909.

parts, steam heaters, fuel oil, and 2 pony trucks, has brought the weight up to 102 tons, of which 77 tons are on drivers.

**Motors** are of the compensated, single-phase, series type. Four are used, each of 240-h. p., 1-hour capacity and 200-h. p. continuous capacity on forced draft. On direct current the rating is about 50 per cent. higher. Voltage for motors is 220 on alternating current, and 300 on direct current, see illustration, Figure 44.

Speed of the motors on rated load is 220 r. p. m. and of locomotive is 40.5 m. p. h. The maximum speed of the locomotive is about 75 m. p. h. Commutator speed at 60 m. p. h. is only 3000 f. p. m. Forced ventilation is used for cooling and to keep out the dirt.

Frames and fields are split horizontally. There are no projecting poles. Field windings are uniformly distributed.

Armatures are gearless and are not mounted on the shaft but are built up on a quill thru which the axle passes, with a 5/8-inch clearance.

**Motor mounting** is well arranged. The field frame is mounted on bearings which surround the armature quill. The field is suspended from the frame of the locomotive by means of four 1 1/4-inch rods, and only 1000 pounds of the field weight is carried on the quill. The motor frame is anchored to the truck, both above and below the axle by these rods, which permit vertical or side motion but prevent excessive bumping strains. The entire weight of the motor is carried on springs.

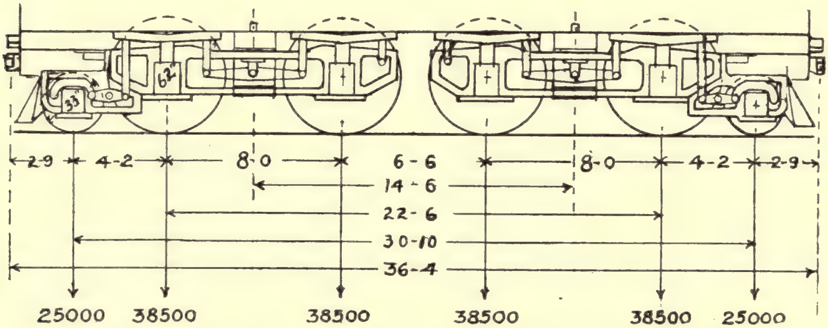


FIG. 136.—NEW YORK, NEW HAVEN AND HARTFORD RAILROAD LOCOMOTIVE, 1909. Forty-one used on New York Division in passenger service. 102-tons, 960-h. p., 1-phase, 11,000-220-volt motors. Gearless, quill-mounted type.

**Armature connection** to the driver is by means of a spider at the ends of the quill, from which spider 7 round pins project parallel to the shaft into corresponding pockets in the hub of the drivers. Around each pin is placed a coil spring about 8 inches in diameter, consisting of 10 turns, progressively eccentric, of 1/2x1/2-inch steel. These springs are contained between 2 steel bushings, the smaller of which slips over the pin and the larger fits in the pocket in the wheel. They carry the entire weight of the motor and transmit the torque of the motor. A vertical movement of about 3/4 inch is allowed for track variation. Hammer blow from the armature, on uneven track, is avoided. Pulsating torque is prevented by the spiral springs. Additional springs placed outside of the driving pins steady the side play.

**Connections and control** of motor circuits are simple. The 4 armatures are arranged in 2 groups, and 2 armatures are connected permanently in series and controlled as a unit. During direct-current acceleration the 2 motor units are connected in series and then in parallel. During alternating-current acceleration, each motor receives power for different speeds by variable voltage from a step-down transformer, no resistance being used. The double control equipment is a handicap.

On direct current the fields are in series with their respective armatures, and they are shunted for high speed; on alternating current the fields of the motors are placed in parallel to decrease the field reactance and also the magnetism per armature ampere. (The reactance varies as the square of the number of field turns on the field, while the strength of the field varies directly as the number of field turns).

FIG. 137.—NEW YORK, NEW HAVEN AND HARTFORD PASSENGER LOCOMOTIVE AND FOUR-CAR TRAIN.

CHART ON LOCOMOTIVE PERFORMANCE.

Passenger Locomotives on New York Division. New York to Stamford.

| A.-C. performance. Speed in miles per hour. Control steps. | | | | | | | D.-C. performance. Speed in miles per hour. Control steps. | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 2. | 3. | 4. | 5. | 6. | **Amperes per motor.** | Series. | Shunt 1. | Shunt 2. | Multiple. |
| .... | 3 | 13 | 24 | 31 | 37 | 2000 | 19 | 24 | 33 | 45 |
| .... | 8 | 19 | 28 | 35 | 40 | 1800 | 20 | 25 | 35 | 46 |
| 4 | 14 | 24 | 32 | 39 | 45 | 1600 | 21 | 26 | 37 | 47 |
| 9 | 20 | 30 | 37 | 43 | 49 | 1400 | 22 | 28 | 40 | 49 |
| 17 | 26 | 35 | 42 | 48 | 55 | 1200 | 23 | 30 | 44 | 51 |
| 25 | 33 | 42 | 49 | 55 | 62 | 1000 | 25 | 34 | 49 | 54 |
| 29 | 37 | 47 | 54 | 60 | 67 | 900 | 26 | 36 | 52 | 56 |
| 35 | 43 | 52 | 60 | 67 | 74 | 800 | 27 | 39 | 56 | 58 |
| 40 | 49 | 59 | 67 | 74 | 81 | 700 | 29 | 42 | 61 | 62 |
| 46 | 56 | 66 | 75 | 83 | 92 | 600 | 32 | 45 | 67 | 67 |

**Charts on locomotive performance** are placed in the front of each passenger locomotive, over the controller. A glance at the control step and at the ammeter gives the running speed.

In alternating-current performance the speed for local and express trains is nominally 60 m. p. h., but the writer has repeatedly observed speeds up to 72 miles per hour when lost time was being regained. Control step No. 6 is commonly used and, with a 6-coach train, about 1000 amperes, corresponding to 62 m. p. h., is an ordinary reading.

In direct-current performance, 30 m. p. h. is the speed allowed by the New York Central rules, between the Grand Central terminal at Forty-fourth Street and Ninetieth Street, or in passing any station; and 45 m. p. h. is the maximum speed allowed in the direct-current zone. Control step marked No. 2 is used for maximum speed, and the meter reading is commonly 1200 to 1100 amperes. The full speed for which the motors were designed is not used, due to the speed restrictions imposed.

PERFORMANCE CHARACTERISTICS OF PASSENGER LOCOMOTIVE.

| Current amperes. | Power factor. | Speed m.p.h. | Tractive effort, lb. | Power h.p. | Notes or conditions. |
|---|---|---|---|---|---|
| 4000 | .725 | 21.0 | 19,700 | 1100 | Four gearless motors, No. 130. |
| 3000 | .810 | 30.5 | 13,300 | 1080 | Voltage 11000/220. |
| 2400 | .842 | 38.3 | 9,800 | 1000 | Series-parallel operation. |
| 2260 | .860 | 40.5 | 8,900 | 960 | One-hour rating, 960 h.p. |
| 2200 | .868 | 41.5 | 8,600 | 950 | ........................ |
| 2000 | .890 | 45.0 | 7,400 | 890 | ........................ |
| 1720 | .915 | 51.5 | 5,900 | 800 | Continuous rating, 800 h.p. |
| 1600 | .926 | 55.0 | 5,200 | 760 | ........................ |
| 1400 | .940 | 61.0 | 4,200 | 680 | Drivers 62-inch. |
| 1200 | .937 | 68.7 | 3,200 | 585 | ........................ |
| 1000 | .970 | 77.5 | 2,400 | 495 | ........................ |

**Operating notes** for service on the New York Division:

Summer schedule calls for about 166 trains per week-day, and the autumn schedule calls for 136.

Electric locomotive miles per engine failure were 14,000, to be compared with steam locomotive miles per engine failure of 6250.

Average miles per month per locomotive owned exceeds 4000. See page 280.

The commutators, while black, are in a very good condition. Brushes make from 22,000 miles on an average, and 34,000 miles as a maximum. Commutators average about 95,000 locomotive miles between turnings.

Tire wear is the principal reason for taking locomotives out of service. Curves on the New York division are many and severe.

Water on the track, from high winds and tides, has at times damaged the wiring. One-fifth of the locomotives, on several occasions during 1908 and 1909, were com-

pelled to run thru water 20 inches deep, for long distances at full speed. The salt water in the motor casings and ducts could have been dried out by the application of the lowest alternating current voltages if the alternating current had been available; but the trouble occurred on the 660-volt, direct-current, third-rail section, and the wiring of first motor of the four in the series would ground.

FIG. 138.—TWO NEW YORK, NEW HAVEN AND HARTFORD PASSENGER LOCOMOTIVES AND 15-CAR TRAIN.

**Inspection** of electric locomotives are made every 12 days, or every 1600 locomotive miles. Steam locomotives require inspection every 100 miles, and must be sent to the back shop for overhaul every 2 months, or about every 40,000 to 60,000 miles, depending upon the service and the water used. Electric locomotives seldom require a general overhaul. The time required for inspection is 4 to 12 hours. Of the 41 passenger locomotives, 3 are in for inspection each day, in summer.

**Maintenance expense,** which includes all repairs, was at first 7 cents per locomotive mile, but this has now been reduced to 5 cents, of which 3.5 cents are for labor and 1.5 cents for material.

**Locomotive troubles** have been detailed and explained by Mr. Murray, Electrical Engineer for the road, to the A. I. E. E., Dec., 1908; Apr., 1911. The new designs had many minor troubles, as was expected, but they disappeared in time. The most wonderful thing about the whole record was the absolute success of the new single-phase motor.

### FREIGHT LOCOMOTIVES 1909–1911.

Three locomotives are being tried out in freight service. These differ from the 41 passenger locomotives in that the motors are mounted above and either geared or crank and side-rod connected to the driving axles, instead of being flexibly mounted on the driver axles. The 2-4-4-2 wheel


FIG. 139.—NEW YORK, NEW HAVEN AND HARTFORD GEARED FREIGHT LOCOMOTIVE, 1909.

FIG. 140.—NEW YORK, NEW HAVEN & HARTFORD GEARED LOCOMOTIVE.
Number 071 hauling the 12-coach "Boston Express."

arrangement is used. These electric freight locomotives on the New York division have much larger capacity than the steam locomotives.

**Specifications** required each electric freight locomotive to be capable of hauling a freight train, having a maximum weight of 1500 tons, at a speed of 35 m. p. h. on level track with 6 pounds per ton resistance; or, when used in heaviest passenger service, to haul an 800-ton passenger train at a maximum speed of 45 m. p. h. and a schedule speed of 40 m. p. h. in limited service, *i. e.* without stops; or to haul a 12-car, 800-ton express-passenger train over the 73 miles between New York and New Haven in 2 hours and 12 minutes, allowing a total of 5 minutes for stops; or to haul a 350-ton train in local passenger service, making all stops, the average of which is not to exceed 45 seconds, over the 73 miles in 2 hours and 45 minutes. Tractive effort was to exceed 40,000 pounds.

## GEARED FREIGHT LOCOMOTIVE 071.

**Trucks** and running gear are planned in accordance with a design patented by S. M. Vauclain, July 6, 1909. This is described as an articulated locomotive in which the two truck frames are connected by an intermediate drawbar, one truck to have a rotative motion about its

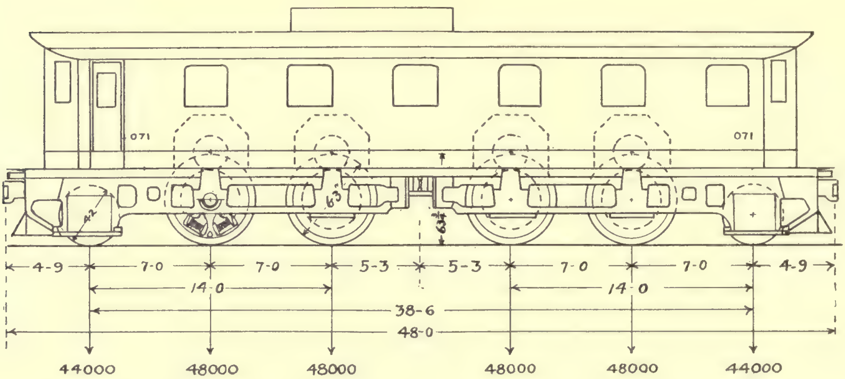


FIG. 141.—NEW YORK, NEW HAVEN AND HARTFORD GEARED FREIGHT LOCOMOTIVE, 1909. One used on New York Division. 140-ton, 1260-h. p., 1-phase, 25-cycle, 11,000–300-volts. Four geared motors. Gear ratio 2.32. Forced ventilation. Freight service.

center pin, while the other has a fore-and-aft motion, as well as a rotative motion, to compensate for the angular positions of the truck and drawbars on curves. Leading wheels are mounted in radial-swing trucks of the Rushton type. The cab is carried thru springs on friction plates at the ends of the trucks, not on the truck center pins. This design also prevents periodic vibration or nosing.

**Wheel loads** are equalized as in steam locomotive practice, the springs

of the leading wheels being connected to the driving springs by equalizing beams. One of the trucks is cross-equalized under the center of the locomotive. The frame is spring-supported by the cross-equalizer on each side of the center line. This arrangement promotes steady riding, and tends to prevent side rolling at high speed.

**Truck wheel base** of geared freight locomotive is 38 feet 6 inches; rigid wheel bases are 7 feet; total wheel base for each truck is 14 feet; truck centers are 24.5 feet; length between couplers is 48 feet. Drivers are 63-inch, and pony wheels 36-inch.

**Frames** are placed outside the wheels, and are braced transversely under the center of the locomotive by heavy steel castings provided with draw pockets in which the intermediate drawbar is seated. This bar transmits from one truck to the other the full tractive force developed by the motors of a leading truck.

**Motors** for the geared freight locomotive consist of 4 single-phase, conductively compensated, series, 300-volt, 1000-ampere, 0.93 power-factor, 315-h.p. units. Each motor with forced ventilation is rated 300-volt, 930-ampere, 0.93-power factor, and 280 h. p. Two motors are used in series. On 350 volts the rating is, of course, materially higher.

The motors have 12 poles built in a solid frame. The diameter of the armature is 39 1/2 inches and the width of the core is 13 inches. The peripheral speed of the armature is high, the armature having the diameter used in the passenger locomotives.

Weight of each motor with gear and gear case and axle bearing but without the 1400-pound quill is 6050 pounds.

Gearing has a ratio of 2.32 and teeth have 1.75 pitch. Gears are placed at each end of the armature shaft. The unit stresses in the gears are much lower than in ordinary large railway motors. Doubt is expressed as to whether there is ample length along the shaft to properly distribute the wear of the teeth, and as to the sufficiency of gears in high-speed service.

**Control apparatus** is of the electro-pneumatic type, designed for use with either 11,000 volts alternating current or 600 volts direct current. When operated on alternating current, the motors are grouped in multiple and the control is obtained entirely by changing the connections to various voltage taps on the main transformer. On direct current the motors are first grouped in series and then 2 in series and 2 in parallel, in combination with various resistance steps. Any one of the motors may be cut out. There are 13 running voltages on the controller or double the number of steps required for passenger service, and any speed can be used continually, with the maximum tractive effort. Two or more locomotives may be coupled and operated from one master controller.

**Motor mounting** is arranged over the axles, and solidly on the truck

frames. Each end of the armature shaft is provided with a pinion meshing with gears mounted on a quill surrounding the axle and carried in bearings on the motor frame, similar to the usual axle bearings. The quills are provided with 6 bearing arms on each end, which project into spaces provided between the spokes in the driving wheels. Each of these arms is connected to an end of a helical spring, the other end of the springs being connected to the driving wheels. This arrangement smooths out the torque pulsations, and it allows for 1 1/2-inch vertical

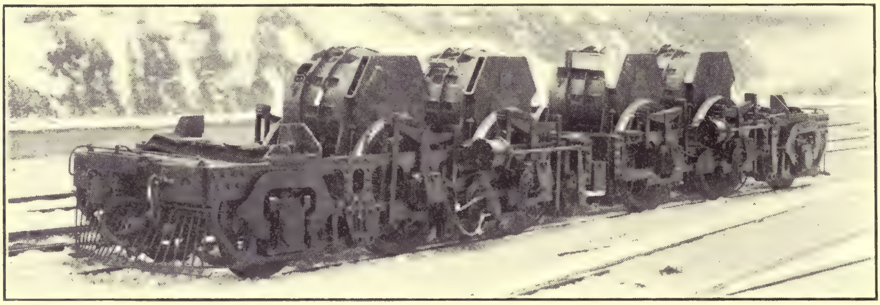

FIG. 142.—NEW YORK, NEW HAVEN AND HARTFORD GEARED FREIGHT LOCOMOTIVE, 1909. Motors and truck for locomotive number 071.

movement of the axles. In addition, flexibility is provided between the quill and motor shafts, to equalize the torque on the gears. The center of gravity of the motors is high. The transmission of strains and shocks from the track to the motors is eliminated.

PERFORMANCE CHARACTERISTICS OF GEARED FREIGHT LOCOMOTIVES.

| Current amperes. | Power factor. | Speed m.p.h. | Tractive effort, lb. | Power h.p. | Notes or conditions. |
|---|---|---|---|---|---|
| 8000 | .660 | 16.5 | 36,900 | 1640 | Voltage 11,000/300. |
| 6400 | .750 | 21.5 | 27,000 | 1540 | Drivers 63-inch. |
| 4800 | .835 | 28.2 | 17,600 | 1340 | Gear ratio 2.32. |
| 4400 | .855 | 30.3 | 15,600 | 1260 | One-hour rating, 1260. |
| 3760 | .885 | 35.0 | 12,000 | 1120 | Continuous rating, 1120. |
| 3200 | .910 | 40.8 | 8,800 | 960 | Motors, 4 No. 403. |
| 2800 | .930 | 46.0 | 6,880 | 845 | Locomotive, No. 071. |

**Tests** have been made on the geared freight locomotives as follows:

A 2100-ton freight train was started and hauled up a 0.3 per cent grade with a 3-degree curve.

A 1600-ton freight train was accelerated at the rate of 0.2 m.p.h.

p. s., or to a speed of 12 m.p.h. in 1 minute; and an 800-ton train was accelerated at a rate of 0.4 m.p.h. p. s.

A maximum tractive effort of 51,000 lb. was developed.

### SIDE-ROD LOCOMOTIVE 070.

A side-rod locomotive was built in 1910 by the Westinghouse Co. for service on the New York Division.

Specifications for the side-rod locomotive were the same as those detailed for the geared freight locomotive.

**The design** is of the articulated double-cab type. Each half comprises 2 pairs of driving wheels and 2 leading pony truck wheels, mounted on a forged frame of the locomotive type. Crankshafts are placed across

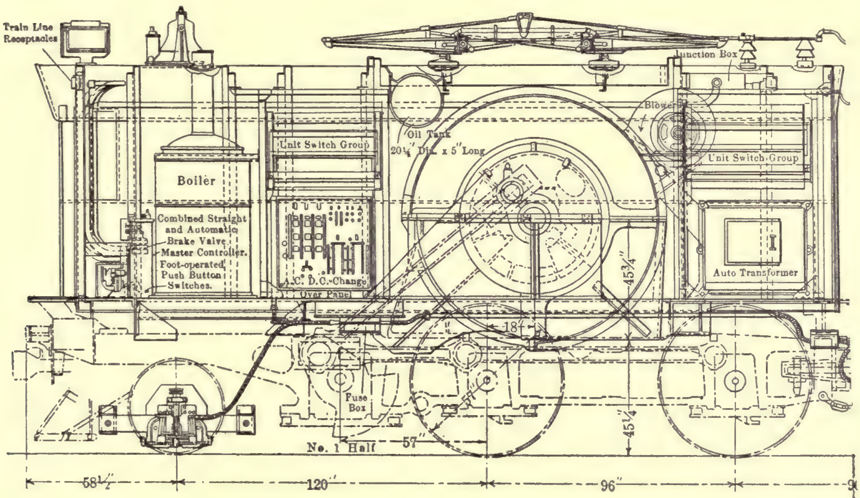


FIG. 143.—NEW HAVEN FREIGHT LOCOMOTIVE, CRANK AND SIDE ROD TYPE. SIDE ELEVATION. One-half of locomotive is shown. Horse power, 1346. Wheel base, 43 feet 6 inches.

the side frames, and 57 inches ahead of the front driving axles, which carry on each end a crank arm and counterweight casting to which a motor crankshaft above is connected by means of rods. The two drivers on each side are coupled to the crankshaft crank pin by locomotive side rods of the ordinary type. The driving mechanism and frames are similar to those on Pennsylvania side-rod locomotives, already described.

**Motors** are single-phase. Two are used per locomotive. With forced ventilation the one-hour rating of each is about 673 h. p. They are arranged for either alternating-current or direct-current service. Either motor may be operated separately. The motor shaft is 91 in. above the rail. Motors are slow-speed units, 206 r. p. m. at 35 m.p.h.,

with 57-inch drivers. Armature diameter is 76 inches. Core has no air ducts and is 13 inches wide. The motor frame is built up of steel plate and standard shapes, in place of the usual steel casting, to gain in rigidity. The rotor is mounted on a quill, and the rotor spider is in 2 parts, between which the spider of the quill shaft is built. The pulsating armature torque is transmitted thru heavy spiral springs at the ends of the spider arms, to smooth out the mechanical effort. Motor transformers are air-cooled, of 150 0-kv. a. capacity.

### GEARED LOCOMOTIVE 069.

A second geared locomotive for main-line freight service was placed in service in 1911.

Specifications were those detailed above for freight locomotives.

The design embodies eight 42-inch drivers on a rigid driver wheel base, and four leading and four trailing pony truck wheels. The pony truck is not pivoted at a bolster, on its vertical center line, but is connected to a V-frame. The pivotal point of the V, and of the pony truck, is at the apex of the V, within the rigid truck wheel base.

Drivers with axle can be removed from the locomotive frame by lowering the wheels, as in steam locomotive practice.

Motors are eight per locomotive. It was found that eight geared, single-phase motors per locomotive made a lighter locomotive than could be built with two or four motors per locomotive. Armatures are the same type as those used for motor-car trains, already described. A single pinion on each armature shaft is connected to a gear wheel which is flexibly mounted on each driver shaft. The motor voltage is 235, or 470 per pair of motors, and the motors are permanently connected in series in pairs.

Framing for the fields of each pair of armatures are of the double horse-shoe shape, mounted rigidly on the locomotive frame.

Weight of this single-phase locomotive, No. 069, is 116 tons, yet this latest design has 40,000-pounds drawbar pull and greater capacity than the other freight locomotives described above.

### GEARED SWITCHER LOCOMOTIVES.

Switcher locomotives are in service at the Harlem River, 62-mile freight yards, electrified in 1911. Tests showed that a 600-h.p. 80-ton unit could handle the yard work.

**The design** embodies two trucks of the heaviest articulated type, suitable for heavy buffing strains, for classification and yard work. It is to be substituted for a steam locomotive which uses an average of 4600 pounds of water per hour, or at 40 pounds per h. p. hour, averages

115 h. p.; but since these locomotives develop power for 36.7 per cent. of the time the average power while working is 313 h. p. Switcher electric locomotives with 450-h. p. *continuous* rating will more than handle the work. The trailing load is 450; the maximum speed, 26 m. p. h.

**Motors** are four, rated 150-h. p. each for one hour, plain, single-phase units of the quill, spring-drive, double-geared type, similar to those on New Haven motor cars, already described under "Motor-car Trains."

COMPARATIVE DATA ON NEW HAVEN ELECTRIC LOCOMOTIVES.

| | | | | | |
|---|---|---|---|---|---|
| Number in service.... | 41 | 1 | 1 | 1 | 15 |
| Number ............. | 01 to 041 | 071 | 070 | 069 | 0200 |
| Service .............. | Passenger | Freight | Freight | Freight | Switch. |
| Wheel order.......... | 2–4–4–2 | 2–4–4–2 | 2–4–4–2 | 4–4–4–4 | 0–4–4–0 |
| Motor connection..... | Mounted on axle quill. | Geared to quill. | Crank and jackshaft. | Geared to quill. | Geared to axle quill. |
| Driver diameter...... | 63-inch. | 63-inch. | 57-inch. | .......... | 63 in. |
| Pony wheel diameter . | 33-inch. | 36-inch. | 36-inch. | .......... | ........ |
| Weight, total........ | 102 tons. | 140 tons. | 35 tons. | 116 tons | 80 tons. |
| Weight on drivers.... | 77 tons. | 96 tons. | 92 tons. | .......... | 80 tons. |
| Weight of motors .... | 33.4 tons. | 38.0 tons. | 41.6 tons. | .......... | 26.0 |
| Weight of armature . . | 5850 lb. | 6050 lb. | 19000 lb. | .......... | ........ |
| No. of motors........ | 4–No. 130 | 4–No. 403 | 2–No. ... | 8–No. 409 | 4-No. 401 |
| One-hour h.p.......... | 960 | 1260 | 1350 | 1396 | 600 |
| Continuous h.p....... | 800 | 1120 | 1130 | .......... | 450 |
| Motor voltage ....... | 220 | 300 | 300 | 235 | 190 |
| Motor shaft above rail. | 31.5 in. | 63.785 in. | 91.0 in. | .......... | 60.0 in. |
| Center of gravity, do.. | 51.0 in. | ...... in. | .... in. | .......... | ........ |
| Diam. of motor...... | 58.5 in. | 58.5 in. | 102.0 in. | .......... | ........ |
| Diam. of armature... | 39.5 in. | 39.5 in. | 76.0 in. | .......... | ........ |
| Length of core....... | 18.0 in. | 13.0 in. | 13.0 in. | .......... | ........ |
| Gear ratio........... | zero | 2.32 | zero | .......... | ........ |
| Rigid truck wheel base. | 8′–0″ | 7′–0″ | 8′–0″ | 11′–0″ | 7′–0″ |
| Total truck wheel base. | 12′–2″ | 14′–0″ | 18′–0″ | 39′–0″ | 23′–6″ |
| Locomotive wheel base | 30′–10″ | 38′–6″ | 43′–6″ | 39′–0″ | 23′–6″ |
| Length over all ...... | 36′–4″ | 48′–0″ | 53′–3″ | 46′–8″ | 37′–0″ |

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Passenger Locomotives: Order for 25, S. R. J., Sept. 9, 1905, p. 638.

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Geared Freight Locomotive: Drawings, E. R. J., Sept. 25, 1909; May 7, 1910, p. 829; Elec. Journal, Feb., 1910; Ry. and Loco. Engrg., April, 1910; Murray: A. I. E. E. April, 1911, pp. 732 and 760.

Side-rod Freight Locomotive: E. R. J., May 7, 1910, p. 830.

Switching Locomotive: A. I. E. E., May 1911, p. 760; Ry. Age, July 21, 1911, p. 119.

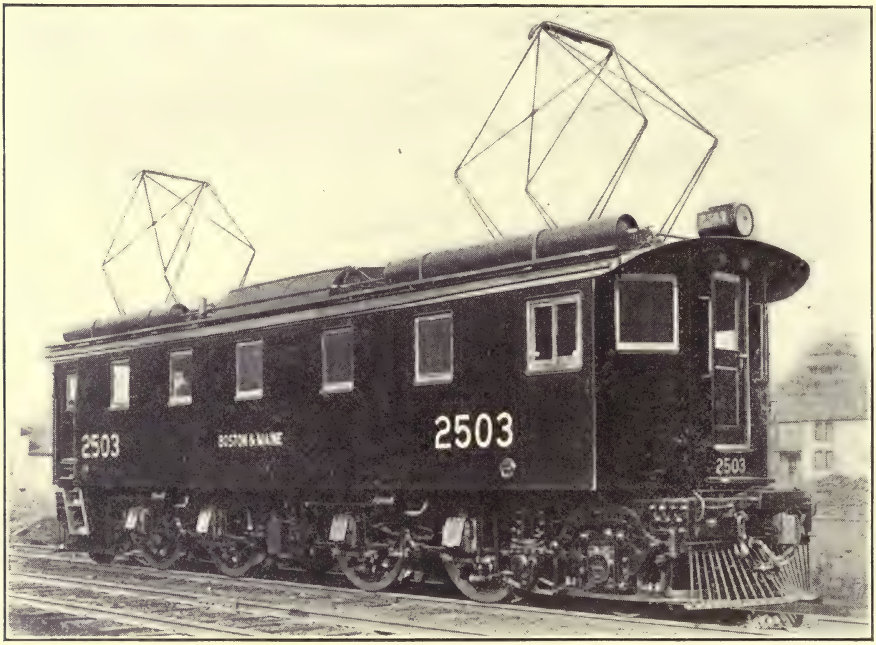


FIG. 144.—BOSTON AND MAINE RAILROAD. GEARED LOCOMOTIVE.

## BOSTON & MAINE RAILROAD.

**Boston & Maine Railroad,** in the electrification of its Hoosac Tunnel in 1911, uses 5 locomotives. They are similar to the New Haven geared freight locomotives No. 071, except that two have a gear ratio of 4.14 in place of 2.32. The design, efficiency, and capacity were raised.

The straight 11,000-volt, 25-cycle single-phase system is used, without the direct-current complications of the controller and third rail.

PERFORMANCE CHARACTERISTICS OF BOSTON & MAINE LOCOMOTIVE.

| Current amperes. | Power factor. | Speed m.p.h. | Tractive effort, lb. | Power h.p. | Notes or conditions. |
|---|---|---|---|---|---|
| 8000 | .82 | 12.2 | 63,500 | 2060 | Voltage 11000/300. |
| 6000 | .88 | 15.1 | 43,000 | 1740 | Gear ratio 4.14. |
| 5000 | .90 | 17.2 | 32,800 | 1520 | Drivers 63-inch. |
| 4250 | .92 | 19.2 | 26,000 | 1340 | One hour h.p. 1340. |
| 4000 | .93 | 20.0 | 23,000 | 1230 | ........................ |
| 3750 | .94 | 21.0 | 21,000 | 1180 | Continuous h.p. 1180 |
| 3000 | .96 | 25.0 | 14,000 | 935 | ........................ |
| 2500 | .97 | 28.6 | 10,000 | 760 | Motors, 4 No. 403........ |


FIG. 145.—VISALIA ELECTRIC LOCOMOTIVE OF 1906.
Fifteen-cycle motors. Swivel trucks

## VISALIA ELECTRIC RAILROAD.

**Visalia Electric Railroad,** owned by Southern Pacific Co., purchased â swivel-truck type electric locomotive in 1908. It is in service between Visalia and Lemon Cove, California,over 36 miles of track.

Weight is 47 tons all on drivers. Wheel arrangement is 0-4-4-0, drivers are 36-inch; rigid wheel base is 7 feet 4 inches.

Motors are single-phase, 15-cycle, the first to be used in America. Four 125-h.p. motors are used. Gear ratio is 3.89. See Figure 37.

Tests were made by starting a 312-ton trailing load on a 10-degree curve, at the foot of a 1 per cent. grade, and hauling the load up the grade; following this test 2 Southern Pacific passenger cars were attached and the tests were repeated by pushing the train around the curve and up the grade. Elec. Ry. Journ., Jan. 15, 1901, p. 101.

### GRAND TRUNK RAILWAY.

**St. Clair tunnel and terminal** of the Grand Trunk Railway has used six 720-h. p. electric locomotives since May, 1908, in and near the St. Clair tunnel which is under the Detroit River between Sarnia, Ontario, and Port Huron, Michigan.

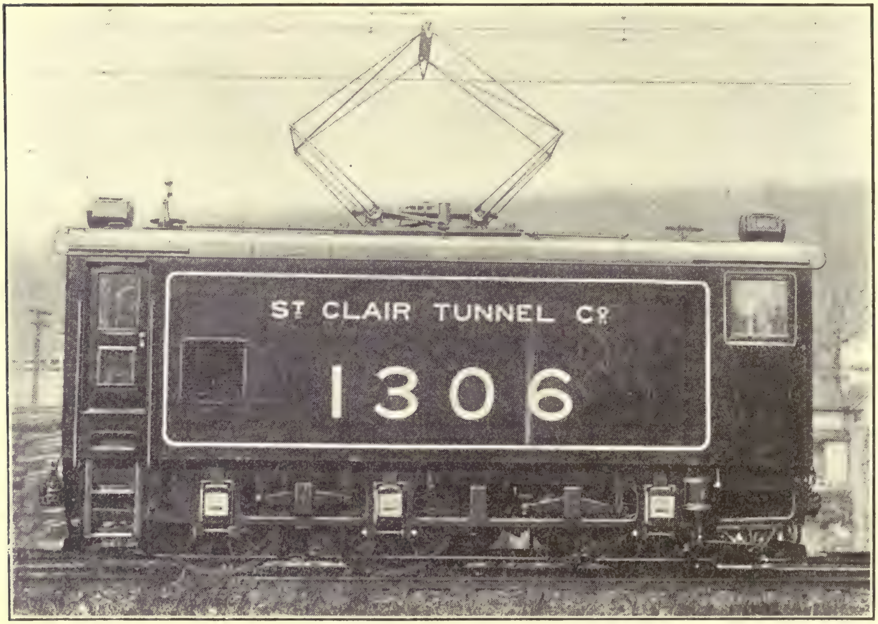


FIG. 146.—GRAND TRUNK RAILWAY LOCOMOTIVE FOR ST. CLAIR TUNNEL, 1906. Six units, 66-ton, 720-h. p. Three 25-cycle, 3000–235-volt, single-phase, geared motors. Tunnel and yard service.

The tunnel is single-track, is 19 feet in diameter, and has a length of 6032 feet. The route electrified is 3.66 miles long and including terminals the mileage is 12. Grades of 2 per cent. for 3000 feet run out of the tunnel.

**The system** used is the single-phase, 25-cycle, with a 3300-volt line. The tunnel was small, and 6000 volts could hardly be used with safety nor was it necessary. The system was chosen by the consulting engineer, B. J. Arnold, on the score of economy of operation.

**Specifications** called for a locomotive with a normal drawbar pull of about 50,000 pounds without sanded track and without slipping the drivers. Two locomotives were to start a 1000-ton freight train on the 2 per cent. grades in the tunnel without taking the slack out of the drawbars and without injury to the commutator or motors.

Weight of the locomotive is about 66 tons, on six 62-inch drivers. Rigid and total wheel base is 16 feet, divided 6 feet 3 inches and 9 feet 9 inches. Weight is equally distributed on axles.

Tractive effort is 3000 pounds at 30 miles per hour; 19,000 pounds at 13.3 m. p. h., at rated load; and 25,000 pounds at 10 m. p. h. Each locomotive on a test developed 45,000 pounds drawbar pull (not tractive effort) before slipping the drivers.

Speed with 500-ton passenger trains varies from a maximum of 25 m. p. h. on the level to 20 m. p. h. up-grade; and with 1000-ton freight trains it is 12 m. p. h. in haulage up the 2 per cent. grade.

**Power plant** contains two 3-phase 1250-kw. turbo-generator units, one of which handles the load. There are four 400-h. p. boilers with double the usual steam storage space, to handle the fluctuating load.

Power required, as shown by tests, is 600 amperes, 3000 volts, and 1500 kw. during 4 to 5 minutes, for a train with 1020 gross tons on a 2 per cent. grade at 11.3 miles per hour. If the resistance, in the tunnel, is 10 pounds per ton, the h.p. is then 1020x50x11.3/375 or 1540. The combined efficiency of transmission and contact lines, motor, and gearing, is 1540x.746/1500 or 77 per cent.

**Motors** are 235-volt, 240-h. p., or 220-volt, 225-h. p. units, with twin gears and a 5.31 reduction. Weight of armature is 5600 pounds, total weight per motor is 14,500 pounds. Motor frames are of the box type, and forced ventilation is provided. Armature is 30 inches in diameter, and the core is 14 3/4 inches wide. (See Fig. 38.)

**Speed control** is secured by voltage variation, by taps from windings of the auto-transformer. Sections are small so as not to cause a large increase of current, or in drawbar pull, while changing taps.

The road is said to handle thru its single-track tunnel the heaviest railroad traffic in the world. With the constantly increasing traffic, at times the four 118-ton steam locomotives were taxed in handling the tonnage, and the capacity of the road was throttled by the tunnel. The installation of the six 720-h. p., 66-ton electric locomotives provides a traffic capacity about three times larger than the actual demands.

PERFORMANCE CHARACTERISTICS OF GRAND TRUNK LOCOMOTIVES.

| Current amperes. | Power factor. | Speed. m.p.h. | Tractive effort lb. | Power h. p. | Notes or conditions. |
|---|---|---|---|---|---|
| 4800 | .800 | 7.7 | 47,700 | 980 | Motors per locomotive, 3. |
| 4000 | .854 | 9.4 | 36,000 | 900 | Drivers, 62-inch. |
| 3600 | .880 | 10.4 | 30,300 | 840 | Parallel operation. |
| 3000 | .905 | 12.1 | 22,300 | 720 | One-hour rating, 720 h.p. |
| 2400 | .940 | 14.6 | 15,200 | 590 | ........................ |
| 2250 | .950 | 15.5 | 13,800 | 570 | Continuous rating, 570 h.p. |
| 2000 | .960 | 17.2 | 11,000 | 510 | ........................ |
| 1600 | .970 | 20.6 | 7,600 | 417 | Gear ratio 5.31. |
| 1200 | .980 | 25.3 | 4,800 | 325 | Voltage 3000/235. |

"Two single-phase 66-ton electric locomotives handle 1000-ton trains, where the 118-ton steam locomotives handled 750-ton trains. The electric locomotives climb the 2 per cent. grades at 10 miles per hour while the steam locomotives were barely able to pull out at 3 miles per hour. The running time from summit to summit is now 10 minutes and the average number of cars per train is 27.3, while under steam conditions the average time was 15 minutes and the average number of cars 19.7." H. L. Kirker, Electrical Review, March 6, 1909, p. 423.

"Train movements thru the tunnel average 26 freight trains per 24 hours, with an average tonnage of 924 per train; and 15 passenger trains per 24 hours with an average tonnage of 281 per train. In freight service two electric locomotives are coupled; in passenger service one locomotive is used. Passenger train and freight business are handled without any interruption." J. F. Jones, Supt. Terminals, 1910.

**Economy** has been obtained with the electric service. Coal cost with electrical operation was 39 per cent. of the coal cost under steam operation. Run of mine and slack Indiana coals are used in power stations, in place of anthracite on steam locomotives. Total service operating charges are 60 per cent. of the charges under steam operation. Total service operating charges plus fixed charges were 84.5 per cent. of the charges under steam operation; and, after adding depreciation, the total operating charges are equal. This is a wonderful result from the first two years' service; with the great investment for a short mileage. Maintenance and repairs of locomotives were reduced 45 per cent.

**Service notes** show that 4 of the 6 locomotives are used regularly. Locomotive inspections are made every third day. Life of pinions is 60,000 miles. Mileage of each locomotive per month averages 2700.

**Safety** has been gained with electrical operation. On account of the large number of trains and the severe braking required on long 2 per cent. grades, trains will break in two, with steam or electric operation. In the event of a train breaking in two with steam, the time necessary to recouple exceeded the interval within which the steam locomotive

could be kept in the tunnel without suffocating the train crew. This trouble is obviated with electric power. It is often necessary for the electric locomotive to start a train on the long 2 per cent. tunnel grades and this is done without first taking the slack out of the train.

**References on Grand Trunk Railway Sarnia Tunnel Locomotives.**

Single-phase Traction: S. R. J. and E. W., Jan. 20, 1906.
Muralt, in criticism: S. R. J., Feb. 17, 1906.
Descriptive: Elec. Journal, April, 1906; Oct., 1908. S. R. J., Nov. 14, 1908.
Power House: Power, June 29, 1909; E. R. J., Nov. 14, 1908, p. 1364.
Kirker: Elec. Review, March 6, 1909, p. 423.
Operation and Shop Methods: S. R. J., April 2, 1910.

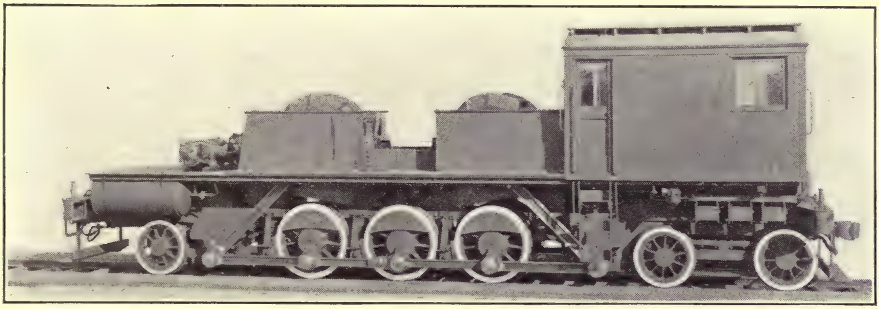

FIG. 147.—GENERAL ELECTRIC SINGLE-PHASE, SIDE ROD ELECTRIC LOCOMOTIVE, 1909.

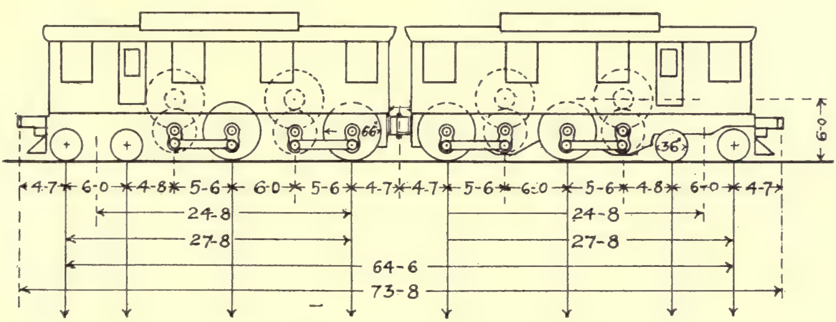


FIG. 148.—GENERAL ELECTRIC LOCOMOTIVE.
Geared side-rod type. Proposed in 1910 for mountain freight service.

## GENERAL ELECTRIC SINGLE-PHASE.

**General Electric Company** built an experimental single-phase locomotive in 1909, which had some distinguishing features.

Frames and running gear were similar to those of a Pacific type steam locomotive with the usual side rods connecting the drivers.

Each motor was crank-connected to a jackshaft, set across the locomotive frames, and connected to the driving wheel side rods.

Motors were two 400-h. p., 15-cycle units set up on the locomotive frames. The design was for passenger service, to deliver 15,000 pounds tractive effort, at 20 m. p. h., but to have variable speed, up to 50 m. p. h. Elec. Ry. Journ., May 8, 1909.

**A geared and side-rod locomotive design,** outlined in the accompanying drawing, was presented at the annual convention of the A. I. E. E., July, 1910. The design embraces: Spring-suspended motor weight; independent operation of driving axles requiring the driving of only one set of wheels at one time; and high weight efficiency due to the introduction of gearing.

## SHAWINIGAN FALLS TERMINAL RAILWAY.

**Shawinigan Falls Terminal Railway,** about 21 miles long, runs from Three Rivers to Shawinigan Falls, half way between Montreal and Quebec.

One General Electric single-phase, 4-motor, swivel-truck, 50-ton locomotive was obtained in 1909 for freight shunting service.

The locomotive is designed for operation on either a 15-cycle or 30-cycle, 6000-volt single-phase circuit.

Motors are rated 150 h. p., 800 amperes, 225 volts on 15 cycles, or 650 amperes and 225 volts on 30 cycles. They have a 4.95 gear ratio.

A trolley voltage of 700 was tried in 1909, but gave trouble in heavy service due to the impedance in the rail return. On 6600 volts and 30 cycles, or on direct current, the operation is successful.

## SWEDISH STATE RAILWAY.

**Swedish State Railway** has been conducting experiments near Stockholm with locomotives and high potential contact lines, since July, 1905.

Westinghouse 18,000-volt, 25-cycle, single-phase, 28-ton, 2-axle locomotive equipment, with 44-inch drivers, was first tested. It was designed to haul a 70-ton train at 40 m. p. h., and was equipped with two 150-h. p. geared motors. A second locomotive had 4 axles, four 44-inch drivers, four 115-h. p., geared motors, and weighed 40 tons.

Siemens-Schuckert furnished a 20,000-volt, 25-cycle, single-phase freight locomotive, shown in the accompanying illustration. The locomotive has 3 driving axles each geared to a 115-h. p., compensated series motor. The locomotive weighs 40 tons and is designed for hauling freight trains at 28 miles per hour. The rated drawbar pull is 13,300 pounds, and on 1 per cent. grades the speed is 15 m. p. h. Drivers are 43-inch. Transformers are oil-cooled, 300-kw. units, and reduce the contact line voltage from 20,000 to from 160 to 320, in 10 sections.

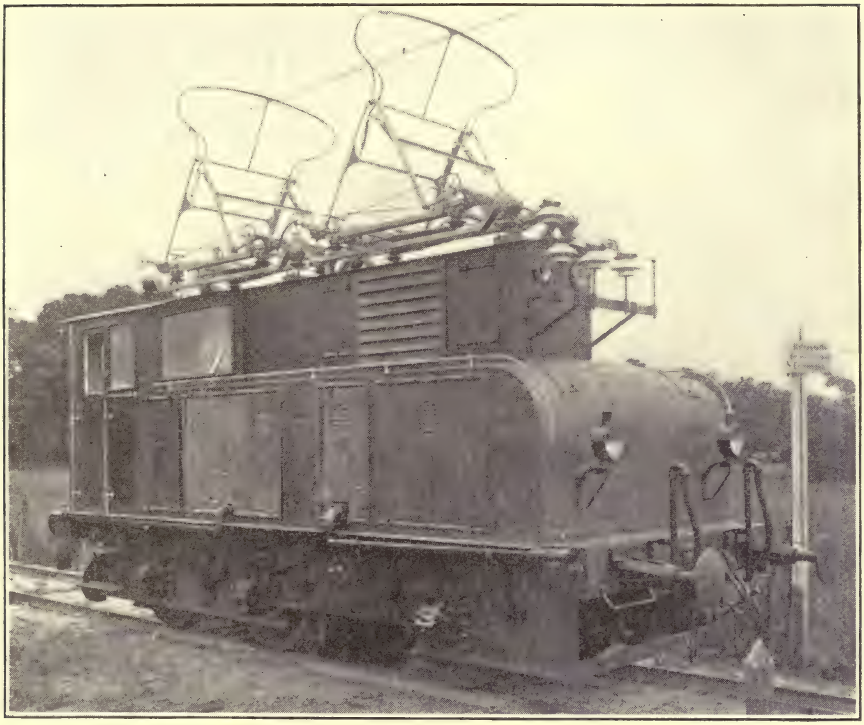

FIG. 149.—SWEDISH STATE RAILWAY. SIEMENS SINGLE-PHASE LOCOMOTIVE OF 1906.

FIG. 150.—SWEDISH STATE RAILWAY. SINGLE-PHASE LOCOMOTIVE AND TRAIN, 1906.

In 1909, as a result of the experienced so gained by the Swedish State Railway, the single-phase, 15-cycle, 15,000-volt system was formally adopted and an extensive program was started, embracing the use of water powers and heavy locomotives for mountain freight trains.

Siemens-Schuckert Works will furnish thirteen 2000-h. p., 110-ton,

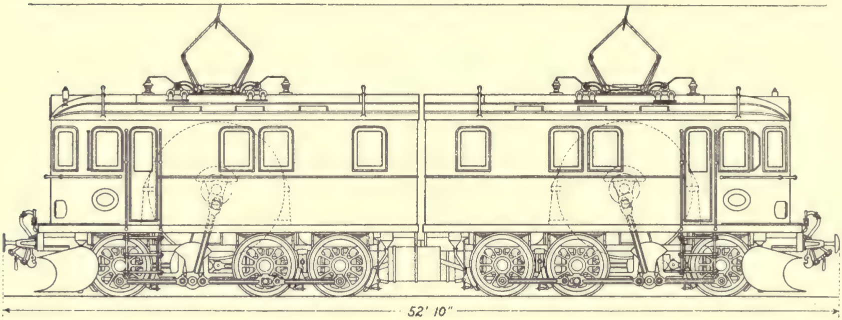


FIG. 151.—SWEDISH STATE RAILWAY. CRANK AND SIDE ROD FREIGHT LOCOMOTIVE. 18,000-volt, 15-cycle, single-phase, 2000-h. p. unit.

crank-type freight, also two 1000-h. p., 77-ton, crank-type passenger locomotives for use on the Kiruna-Riksgransen, 93-mile road on the Norwegian Frontier. The train loads of the ore trains will be doubled. Reference: E. R. J., May 6, 1911, p. 788.

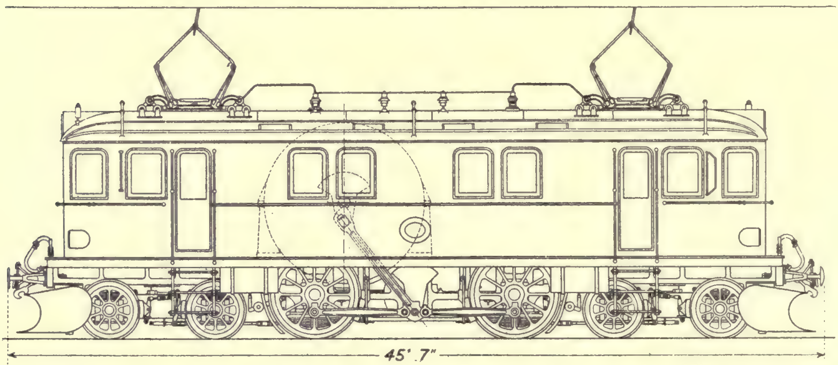


FIG. 152.—SWEDISH STATE RAILWAY. CRANK AND SIDE ROD PASSENGER LOCOMOTIVE. 18,000-volt, 15-cycle, single-phase 1000-h. p. unit.

## FRENCH SOUTHERN RAILWAY.

**French Southern (or Midi) Railway,** in 1911, placed in service one A. E.G. and six Westinghouse geared locomotives. These are 2-motor, 2-6-2 class, crank and side-rod units, equipped with two 800-h. p. single-phase, 15-cycle motors, supplied from a 12,000-volt contact line. Freight

and passenger trains are hauled on a 70-mile, double-track mountain road.

Specifications required that, between speed limits of 18 and 33 m. p. h., when traveling on down-grades, current be returned to the line; also

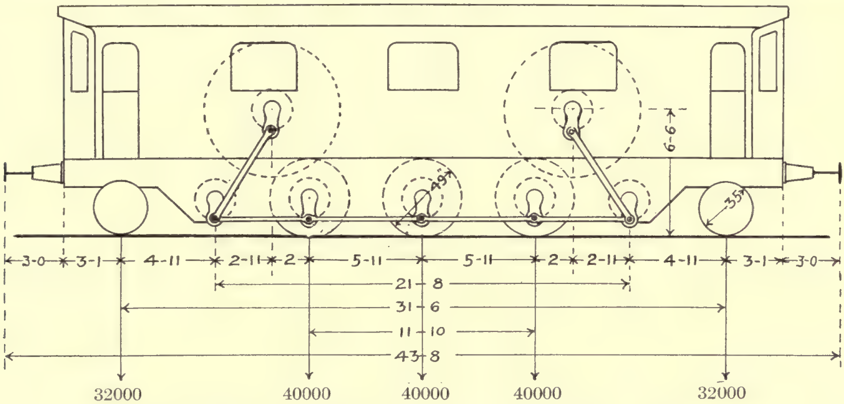


FIG. 153.—FRENCH SOUTHERN RAILWAY LOCOMOTIVE, 1910.
Used between Pau and Montrejean. A. E. G. 94-ton, 1600-h. p., 1-phase, 15-cycle, 12,000-volt locomotive of the side-rod type. Forced ventilation. Freight and passenger service.

that a 450-ton train be hauled up a 3.5 per cent. grade at 18 m. p. h.; a 310-ton train at 25 m. p. h.; and a 115-ton train at 38 m. p. h. On the level, express passenger trains were to run at 62 m. p. h., and regular passenger trains at 40 m. p. h.

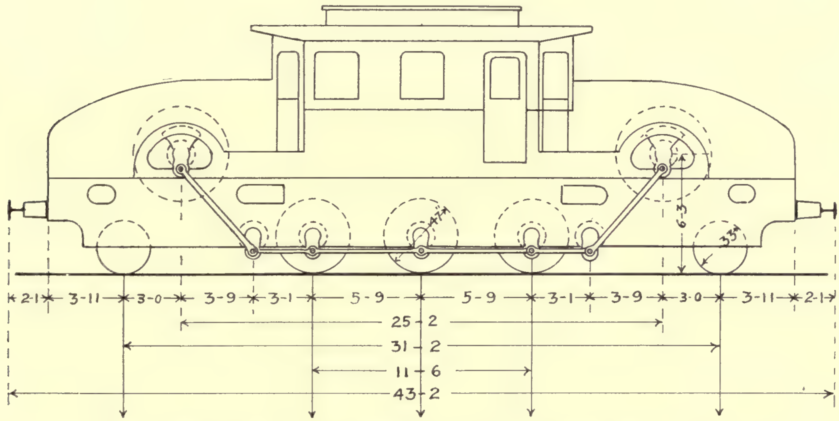


FIG. 154.—BADEN STATE-WEISENTAL RAILWAY LOCOMOTIVE OF 1910.
Ten Siemens-Schuckert units used on the Basel-Zell Line. 71-ton, 1050-h. p., 300-volt motors.

Westinghouse units weigh 89 tons, of which 62 tons are on drivers.

A. E. G. units weigh 94 tons, of which 60 tons were on 49-inch drivers.

The cranks work at an angle of 45 degrees with the horizontal, and the crank circle has a 21.66-inch diameter. E. R. J., June 3, 1911, p. 962.

## GERMAN STATE RAILWAYS.

**Baden State Railway** in 1909 obtained from Siemens-Schuckert ten locomotives for its Wiesental Railway between Basel, Schopfheim, and Zell, 34 miles of track.

The system is the 15-cycle, 10,000-volt, single-phase. Locomotives have 3 sets of 47-inch drivers and 2 sets of leaders. Motors are two 525-h. p., 300-volt, mounted upon the locomotive frame and crank-connected to jackshafts and to driver side rods. Weight is 71 tons. Eighty 250- to 540-ton trains per day are hauled up grades of 0.57 per cent.

Other locomotives of about the same capacity, weight, and type were purchased from Allgemeine Electricitats Gesellshaft.

### Reference.

Electrician, July 2, 1909; Ry. Age Gazette, July, 1909; E. R. J., Dec. 11, 1909; Apr. 9, 1910, p. 668; Zeitschrift, Jan., 1909.

Fig. 155.—Bavarian State Railway. Siemens Locomotive on Murnau-Oberammergau Line, 1905.

**Bavarian State Railways** in 1905 equipped the Murnau-Oberammergau line with two Siemens-Schuckert, 2-axle locomotives for freight service, each with 175-h. p. 15-cycle motors, with a gear ratio of 5. The trolley voltage is 5500. Many interesting details of the locomotive, contact line, and 2-axle freight cars are shown in the illustration.

**Prussian State Railway** in 1906 ordered from the A. E. G. two 25-cycle, 6000-volt experimental locomotives. One had three 350-h. p., and one had two 300-h. p., single-phase motors. The first locomotive, in service at Oranienburg, is shown in Figure 196. It has geared motors, 56-inch drivers, 10-foot 10-inch bogie truck wheel bases, a 31-foot total wheel base, and weighs 66 tons.

For the Magdeburg-Leipzig Line, Brown-Boveri, Allgemeine, Oerlikon, and Siemens Companies have built locomotives of the 2-motor, crank type,

and the Bergmann Company has built a 1-motor, 1500-h. p. locomotive. These locomotives were designed for 75 m. p. h. in passenger service, and for 35 m. p. h. in freight service.

The 10,000-volt, 15-cycle system has been adopted.

**Allgemeine** has furnished an express locomotive of the Atlantic type and 4–4–2 class. One 1000-h. p. motor, mounted in the center of the locomotive, utilizes *vertical* driving rods from its crank shafts, and a crank circle of 23.6 inches. The crank shaft is side-rod connected to 2 pairs of 63-inch drivers. Rigid driver wheel base is 9 feet 10 inches, and total wheel base is 19 feet 8 inches. Weight is 77 tons. See Figure 157.

FIG. 156.—PRUSSIAN STATE RAILWAY. A. E. G. LOCOMOTIVE AT ORANIENBURG, 1906.

Allgemeine freight locomotive is of the 0–4–4–0 class, with one 800-h. p. motor, crank-connected at 45 degrees to a crankshaft located across the middle of the locomotive. The crank circle diameter is 19.7 inches. The crank shaft is side-rod connected to 4 pairs of 41-inch drivers. Driver wheel base, not rigid, is 15 feet 9 inches, and the total weight is about 64 tons. See Figure 158.

**References.**

Elec. Zeit., Aug. 4, 1910; E. W., April 9, 1910; E. R. J., June 6, 1908, p. 11.

## SWISS FEDERAL RAILWAY.

**Swiss Federal Railway** has experimented extensively on the Seebach-Wettingen branch, with Oerlikon and with Siemens locomotives.

An Oerlikon locomotive, built in 1905, is a plain, single-phase, 15-cycle unit with 2 bogie trucks. It has two 200-kv. a., 15,000 to 600-volt transformers. Two 250-h. p., 650-r. p. m. forced draft motors, with

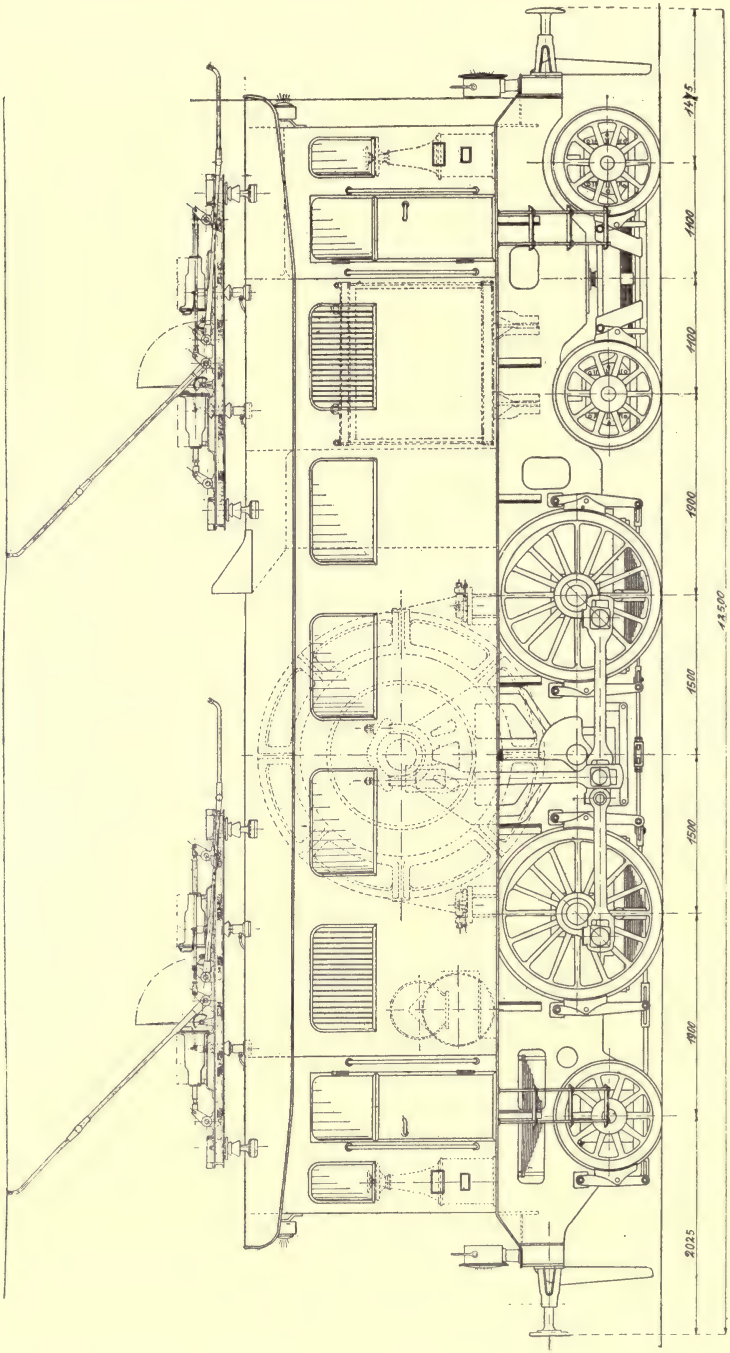


FIG. 157.—PRUSSIAN STATE RAILWAY. E. A. G. PASSENGER LOCOMOTIVE, 1910.
Used on the Magdeburg-Leipzig Road. A 77-ton, 1000-h. p., unit, 1-phase, 15-cycle, 10,000-300-volt motor for crank and side-rod connection.

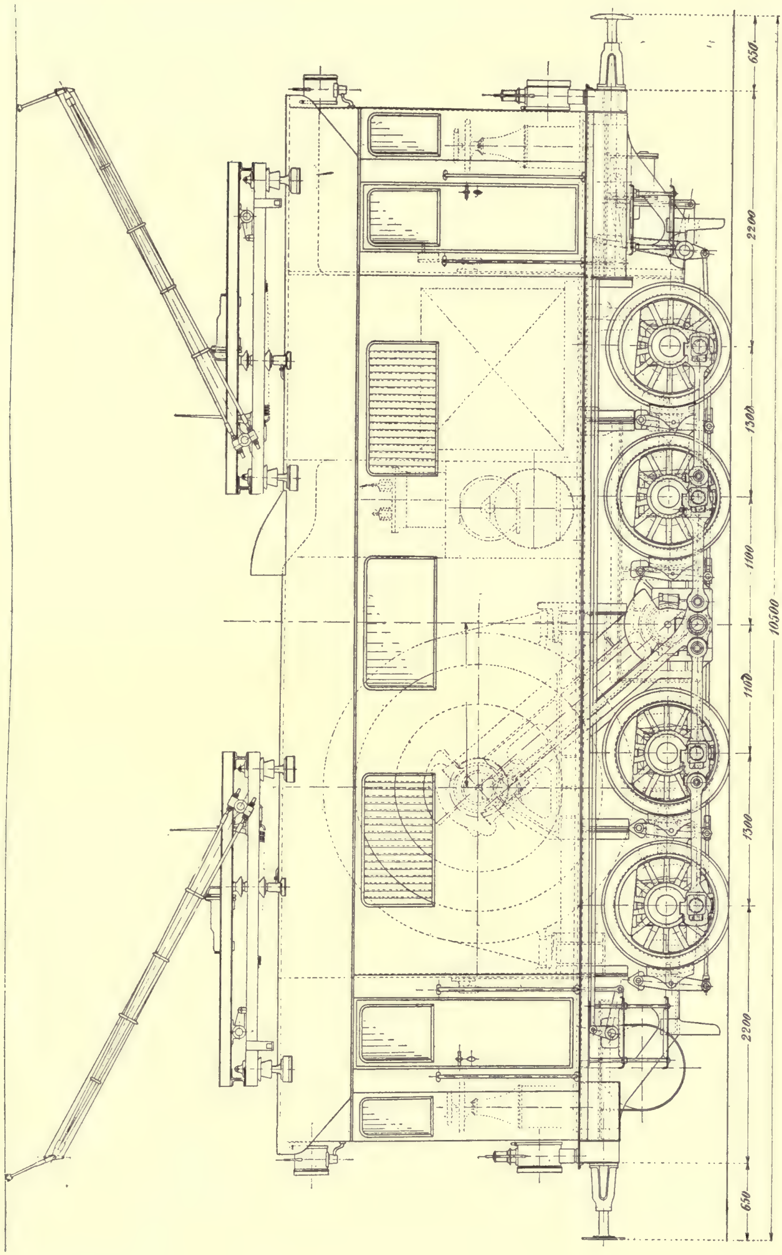


FIG. 158.—PRUSSIAN STATE RAILWAY. E. A. G. FREIGHT LOCOMOTIVE, 1910.
Used on the Magdeburg-Leipzig Road. A 64-ton, 800-h. p., 1-phase, 15-cycle, 10,000-300-volt motor for crank and side-rod connection.

Fig. 159.—Swiss Federal Railway. Siemens Locomotive, 1906.

Fig. 160.—Swiss Federal Railway. Siemens Single-phase Freight Locomotive.

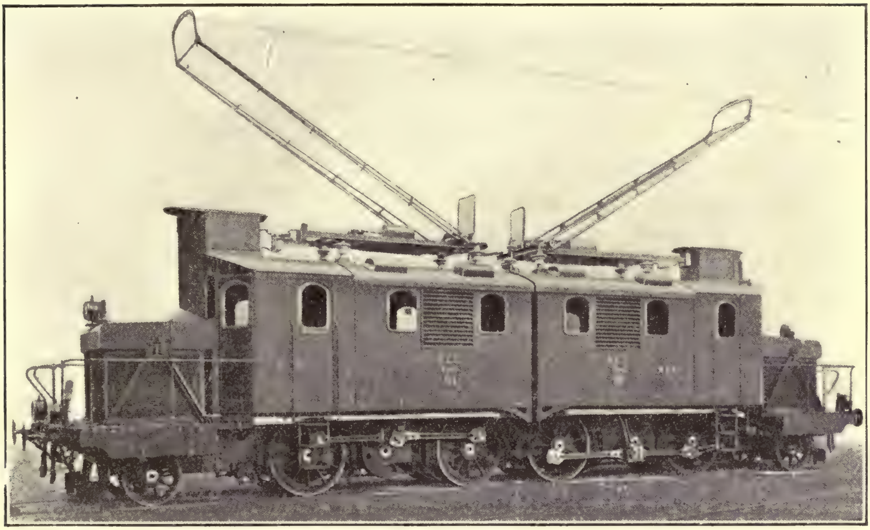

FIG. 161.—BERNESE ALPS RAILROAD. A. E. G. SINGLE-PHASE LOCOMOTIVE, 1910. 1600-h. p., 103-ton, crank and side-rod units. Crank rods from motors make an angle of only 11 degrees from a vertical.

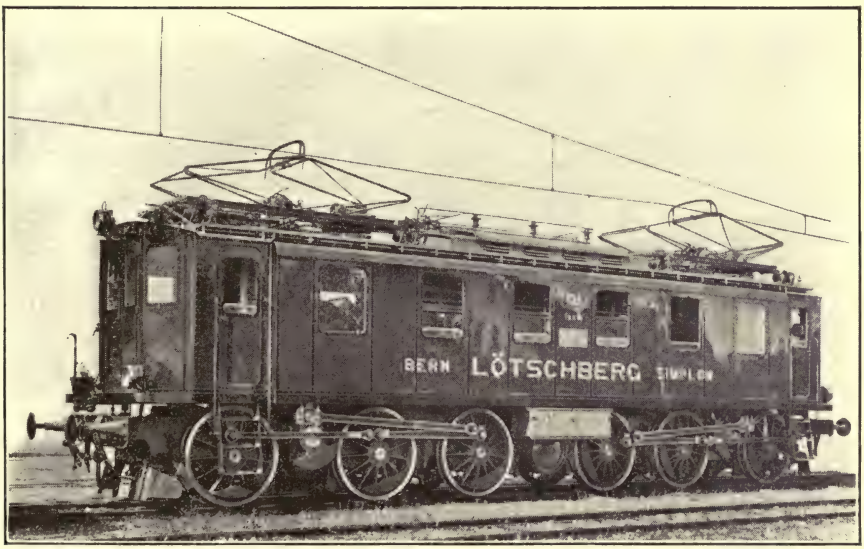


FIG. 162.—BERNESE ALPS RAILROAD. OERLIKON SINGLE-PHASE LOCOMOTIVE, 1910. 2000-h. p., 97-ton, crank and side-rod units.

a 3.08 gear ratio, are geared to a crankshaft located between each pair of 40-inch drivers, the crankshaft being coupled by side rods to the drivers. Weight of electrical equipment is 18 tons and the total is 45 tons.

A motor-generator locomotive is described later in this chapter.

A Siemens freight locomotive, Figures 159 and 160, is a 6-axle, 83-ton, single-phase, 15-cycle, 15,000-volt, 1350-h.p. unit. Each of six 225-h.p. motors is geared to its axle, a 3.75 gear ratio being used. E. W., Aug., 1908, p. 290.

### BERNESE ALPS RAILROAD.

**Bernese Alps Railroad,** in 1910, placed in service several locomotives on the 52-mile road between Bern, Lotschberg, and Simplon Tunnel.

**A. E. G. Locomotive.** This unit is of the articulated 2-4-4-2 class.

Specifications called for 28,600 pounds maximum tractive effort,

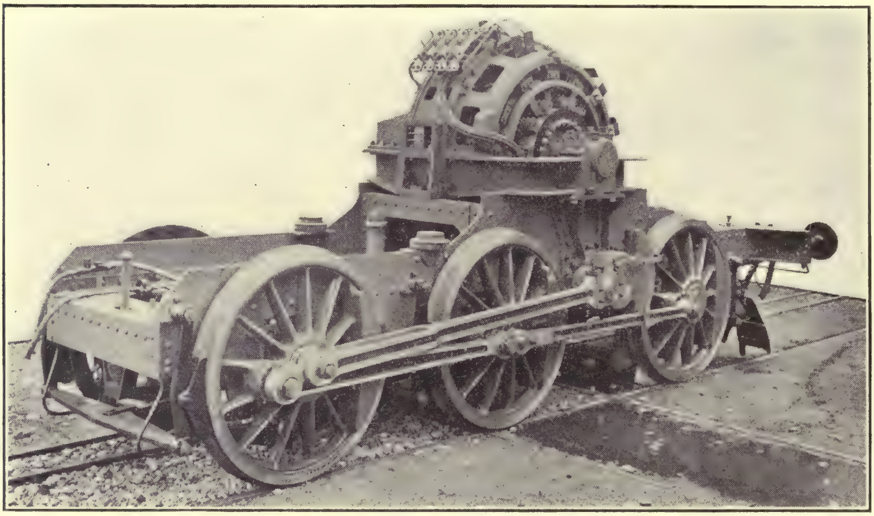

FIG. 163.—BERNESE ALPS RAILROAD. MOTOR AND TRUCK OF OERLIKON LOCOMOTIVE.

and a 1-hour drawbar pull of 17,600 pounds, at 24.8 miles per hour, for a 2.7 per cent. grade and 280-ton train, or for a 1.55 per cent. grade and 442-ton train; and for maximum speeds of 47 m. p. h.

The design embraces a unit built in two similar halves, with two 800-h.p. motors mounted upon the frames, which transmit their energy by crank and connecting rods, thru crankshaft. Each pair of driving axles is side-rod connected. Leading wheels are used on a pony truck and the leading axles are sliding axles. The driving axles can turn independent within narrow limits. The side rods have the usual knuckle joint. Springs are provided to keep the driving axle at right angles to the

longitudinal axis of the locomotive, on tangents. Driver wheel diameter is 50 inches; leading wheels, 33 inches; crank circle, 21 inches; wheel base, 40 feet 10 inches; wheel base of one-half, 17 feet 4 inches; weight on driving axles, 19 tons; on leading axles, 14 tons; total weight 103 tons; weight of mechanical portion, 49 tons; weight of electrical equipment, 54 tons; weight of motors, 30 tons.

Motors are two 8-pole 800-h.p., single-phase, 15-cycle units, fed from two 15.000- to 400-volt transformers. E. R. J., April 9 and Oct. 29, 1910. See Fig. 33.

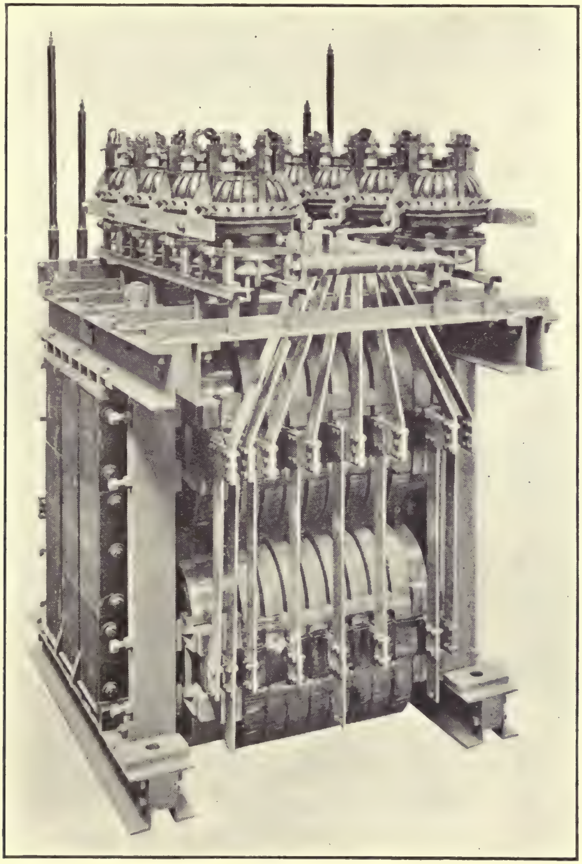

FIG. 164.—BERNESE ALPS RAILROAD. TRANSFORMER ON OERLIKON LOCOMOTIVE.

**Oerlikon Locomotive.** This unit is of the two truck 0-6-6-0 class. The two bogies each have three coupled axles. Weight is 97 tons, all on drivers; mechanical parts weigh 49 tons, and electrical parts 48 tons. Two 15,000- to 450-volt, 1000-kv.a. transformers weigh 12 tons. Length is 48 feet. Drivers are 53-inch. Motors and transformers are located over the two sets of end drivers of each truck; and the weight on the leading and trailing axles is 14.5 tons, while that on each of the four middle axles is 16.8 tons. Axle centers in feet and inches are 5-5, 6-0, 8-7, 6-0, 7-5.

**Motors** are two 12-pole, 1000-h.p., single-phase, 420-volt, 2100-ampere, 510-r.p.m., compensated series, 11-ton units. Frames are split horizontally. A 10-h.p. motor operates a forced draft fan for motors and transformers. Temperature rise is 60° C. for commutator and stator, and 75° for the rotor. Power factor for speeds above 20 m.p.h. is 95 per cent. Air gap is 3 millimeters and thickness of babbit in bearings is 2 millimeters.

Motor shafts are 73 inches above the rail. Efficiency is .90 at half and full load, and .95 at 19 m.p.h. Motors are rated 2000-h.p. Gear shafts are 10.4 inches

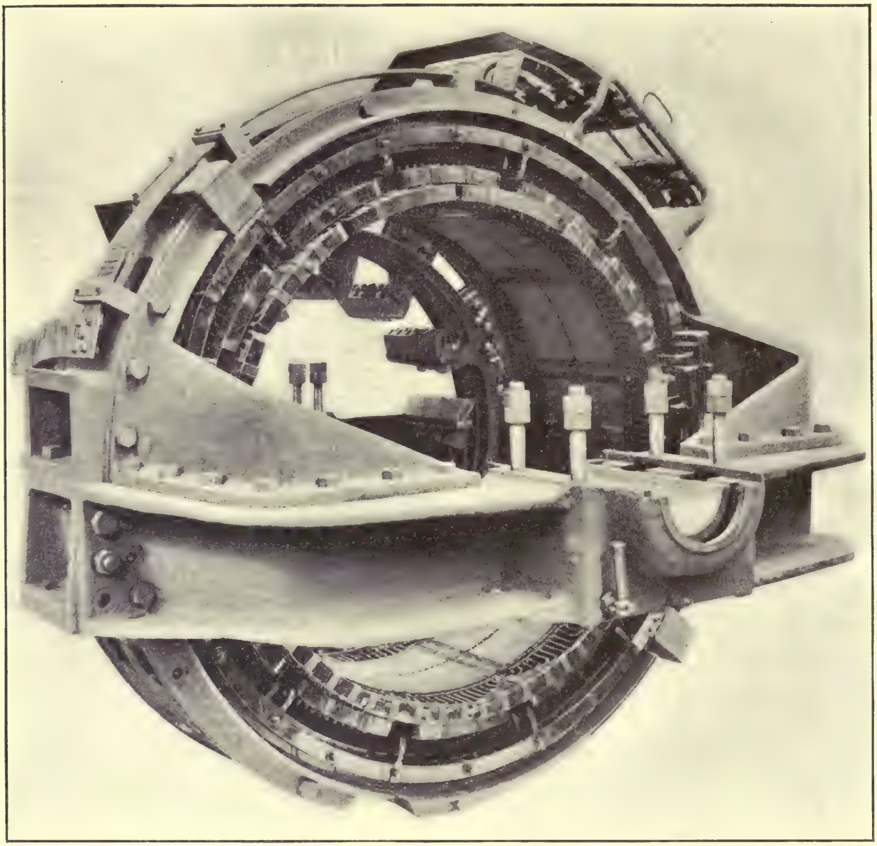

FIG. 165.—BERNESE ALPS RAILROAD. OERLIKON LOCOMOTIVE. MOTOR WITH ARMATURE REMOVED.

above the plane of the driver-axle centers. Each gear axle is crank connected to the further driver axle thru a 9-foot crank rod, which is forked at the driver end, and connects to a crank pin on the side rod. Side rods connect the three axles.

Gear ratio is 3.25 and gear teeth are waved-shaped, consisting of a double angle with rounded tips, the sides being at an angle of about 45 degrees. Maximum pressure on teeth is 1850 pounds per square inch. Gear wheels are 57 inches in diameter. Motors run equally well on direct current at 400 volts and on one phase of a three-phase circuit. They are the largest motors yet built and have a remarkably high weight efficiency.

**References:** E. W., Nov. 17, 1910, p. 1191; E. R. J., June 18, 1910; July 29, 1911.

**Performance tests** show a maximum tractive effort of 33,000 pounds, and a normal tractive effort of 28,800 pounds at 26 m.p.h. or 2000 h.p. By utilizing a quickly made modification of the secondary transformer windings, to provide for a higher voltage 3000 h.p. can be exerted for an hour at a speed of 37 m.p.h., and motors then have a 2000-h.p. continuous rating. (Oerlikon Bulletin No. 63, August, 1910.)

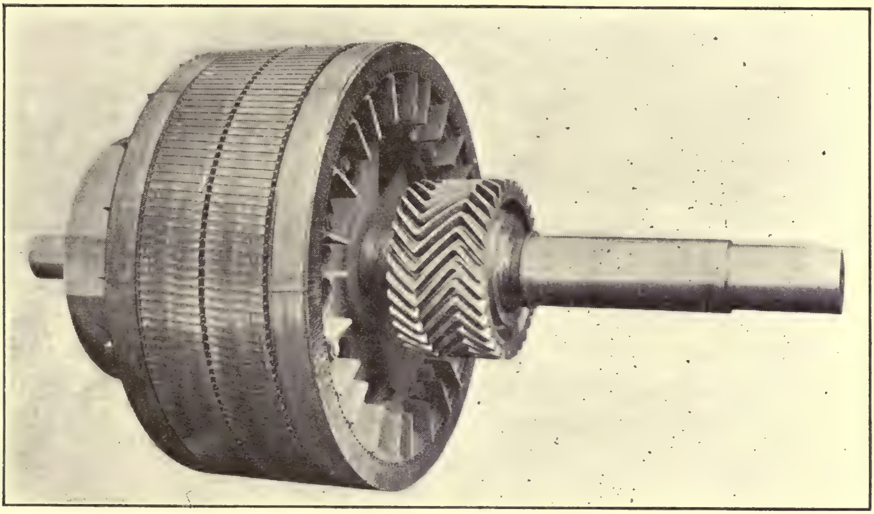

FIG. 166.—BERNESE ALPS RAILROAD. ARMATURE AND PINION ON OERLIKON LOCOMOTIVE MOTOR.

COMPARISON OF OERLIKON WITH OTHER LOCOMOTIVES.

| Name of railroad. | Name of mfgr. | Electric system. | One hour h.p. | Continuous h.p. | Wt. in tons. | 1-hour per ton. h.p. | Max. speed m.p.h. | Wt. of motors tons. | Wt. of transf., tons. |
|---|---|---|---|---|---|---|---|---|---|
| New York Central | G.E. | D.C. 600–v. | 2200 | 1000 | 115 | 19.1 | 60 | 25 | 0 |
| Pennsylvania | West. | D.C. 660–v. | 2500 | 1600 | 157 | 15.9 | 66 | 43 | 0 |
| Giovi | West. | 3–p. 25–cy. | 1980 | 1440 | 67 | 29.5 | 28 | 27 | 0 |
| Simplon Tunnel | Brown | 3–p. 15–cy. | 1700 | ....... | 76 | 22.4 | 43 | 27.5 | 6.6 |
| Great Northern | G.E. | 3–p. 25–cy. | 1700 | 1500 | 115 | 14.8 | 15 | 30 | 10 |
| Boston & Maine | West. | 1–p. 25–cy. | 1340 | 1180 | 130 | 10.3 | 50 | 38 | ...... |
| French Southern | West | 1–p. 15–cy. | 1600 | 1200 | 89 | 18.0 | 46 | 30 | 9 |
| Bernese Alps | A.E.G. | 1–p. 15–cy. | 1600 | ....... | 103 | 15.5 | 46 | 30 | ....... |
| Bernese Alps | Oerlikon | 1–p. 15–cy. | 2000 | 2000 | 97 | 20.6 | 44 | 21 | 12 |

Continuous h.p. rating of alternating-current motors is on forced draft.
Maximum speed must be considered in comparing the locomotive tonnage.

## ST. POLTEN-MARIAZELL RAILWAY.

**St. Polten-Mariazell Railway** in lower Austria, a 30-inch gage road, 67 miles long, in 1910 changed from steam locomotives which had a maximum speed of 18.6 m.p.h. to single-phase, electric locomotives with a maximum speed of 30 m.p.h. Siemens-Schuckert Works has furnished 17 locomotives. Two units are used with multiple-unit control for all heavy trains. Each unit has two 6-wheel, swivel trucks.

Motors are two per locomotive, 250-h.p., 250-volt, series type with forced ventilation, mounted above the truck frame between the middle and inside driving axle. Motors have a 2.9 gear ratio and are geared to crankshafts, each of which is outside connected to 3 pairs of drivers by side rods. The rigid wheel base of each truck is 7 feet 10 inches, and, as is usual in European practice, the forward driving wheels are connected to the middle wheels by a side rod thru a knuckle joint. The total wheel base is 25 feet 10 inches.

Weights are: total, 99,500 pounds; mechanical 46,500 pounds; motors and gears, 26,500 pounds; two 6000- to 250-volt transformers, 15,500 pounds; control apparatus, 8800; current collectors, 2200 pounds; each motor, 4400 pounds. Elec. Ry. Journ., August 20, 1910.

## LEONARD-OERLIKON.

**Motor-generator locomotives** usually embrace:

High-pressure single-phase distribution. Single-phase, direct-current, self-starting, continuous-running motor-generator; driving direct-current motors connected to axles. Regeneration of energy by field control of the direct-current generator.

Advantageous features of the motor-generator plan:

Sixty-cycle current may be used if necessary. Wasteful resistance losses are avoided in acceleration. Smooth acceleration is obtained for freight-train haulage. Opening of all heavy current circuits is avoided. Variations in speed may be produced by variation in the shunt fields of the direct-current generators. Multiple-unit control is simplified. Regeneration of energy is facilitated.

A motor-generator locomotive was built in 1905 by the Oerlikon Company for the Seebach-Wettingen Railway of Switzerland. The line voltage, 15,000, was reduced by two 15-cycle, 200-kw. transformers to 750 volts. The motor-generator set was rated 520 h. p., and consisted of a squirrel-cage, single-phase motor connected to a 600-volt direct-

current generator, rated 400 kw. at 980 r. p. m. There were four 100-h. p., 600-volt, direct-current traction motors, with a 3.50 gear ratio, connected in pairs to coupled drivers. Drawbar pull was 9000 pounds, and the running speed was 44 m. p. h. Weights are given below:

| | | |
|---|---|---|
| Mechanical parts | 22.2 tons | 42.6 per cent. |
| Transformers | 3.0 tons | 5.8 per cent. |
| Motor-generator | 11.0 tons | 21.2 per cent. |
| Axle motors | 15.8 tons | 30.4 per cent. |

The total weight was 52 tons, which is only 7.7 h. p. per ton.

### References on Leonard-Oerlikon Locomotives.

Leonard, A. I. E. E., June, 1892; E. W., March 5, 1904; July 8, 1905, p. 50.

Oerlikon, S. R. J., April 8, 1905, p. 650; Nov. 11, 1905, p. 888; S. R. J., Feb. 24, 1906; E. W., Aug. 8, 1908.

## PARIS-LYONS-MEDITERRANEAN.

**Paris-Lyons-Mediterranean Railway** built an experimental locomotive in 1909 which embodied a modified electric system.

A single-phase, alternating-current, 12,000-volt, 25-cycle contact line delivers power to a locomotive, on which a permutator converts the alternating current to direct current at an e. m. f. adjustable between zero volts and 600 volts. The energy is delivered to 4 ordinary direct-current, 450-volt motors geared to the 4 driving axles of the locomotive.

The regulating permutator which is used consists of a synchronously revolving commutator which makes one revolution per cycle. The function of the permutator is to reverse the current every half cycle or to send the successive half waves of alternating current in the same direction to a receiving, direct-current circuit. The permutator which has a normal power factor of 98 per cent. is rated 2200 kw.; it weighs 20 tons.

The locomotive weighs 140 tons, is 65 feet long, and has 8 axles of which the 4 central ones are the driving axles. The drawbar pull exerted is 16,400 pounds at 37 miles per hour and 10,600 pounds at 62 miles per hour. This locomotive and system are used on the Grasse-Cannes-Mouans-Sortoux line with steep grades and sharp curves.

### Reference.

London Electrician, October 22, 1909; March 17, 1911; S. R. J., Dec. 1, 1906.

## REFERENCES TO DETAILED DRAWINGS OF SINGLE-PHASE LOCOMOTIVES.

| Name of locomotive. | Maker. | Location. | References. |
|---|---|---|---|
| New Haven 1906 pass. | West. | New York Div. | E.R.J., Aug. 17, 1907; Nov. 21, 1908. |
| 1909 geared | West. | New York Div. | E.R.J., Sept. 25, 1909; May 7, 1910. |
| 1910 crank | West. | New York Div. | E.R.J., May 17, 1910, p. 830. |
| 1911 switch | West | Harlem Yards | E.R.J., April 15, 1911, p. 667. |
| Boston & Maine geared | West. | Hoosac Tunnel | |
| Grand Trunk geared | West. | St. Clair | |
| Windsor, Essex & L.S | West. | Windsor Ont. | E.R.J., July 25, 1908, p. 340. |
| General Electric freight | G.E | Proposed | A.I.E.E., July, 1910, p. 1788. |
| | | Proposed | E.R.J., May 8, 1909, p. 874. |
| Prussian State | A.E.G. | Oranienburg | Zeitschrift, 1908, p. 17. |
| | | Magdeburg | E.R.J., Dec. 25, 1909, p. 1259. |
| French Southern | A.E.G. | France | E.R.J., April 9, 1910.<br>Zeitschrift, Jan., 1909, p. 998. |
| Baden State, Wiesental | Siemens | Basel-Zell | E.R.J., April 9, 1910. |
| Bernese-Alps | A.E.G | Loetschberg | E.R.J., April 9, Oct. 29, 1910. |
| Bernese-Alps | Oerlikon | Loetschberg | E.R.J., June 18, 1910. |
| St. Polten-Mariazell | Siemens | Austria | E.R.J., Aug. 20, 1910, p. 301. |

*This page is reserved for additional references and notes on single-phase locomotives.*

## CHAPTER XI.

# POWER REQUIRED FOR TRAINS.

### Outline.

**Power Units and Formulas.**

**Power for Trains a Function of:**

Weight of cars; speed of train; tractive coefficient, character of tractive effort; tractive resistance, gravity, friction, inertia; acceleration, deceleration.

**Elementary Kinematics of Acceleration.**

**Energy for Frequent Stops.**

**Power for Auxiliaries:**

Light, ventilation, brakes, electric heating.

**Losses at Motors:**

Mechanical, magnetic, electric, control, contact.

**Losses Beyond Motors:**

Transformation, conversion, transmission.

**Power Curves:**

Speed, tractive effort, time.

**Watt-hours per Ton-mile.**

**Regeneration of Energy:**

Mechanical and electrical schemes.

**Summary on Power Required.**

**Literature.**

## CHAPTER XI.

# POWER REQUIRED FOR TRAINS.

### IN GENERAL.

The tractive effort required to overcome train resistance will first be studied; after which the tractive effort to overcome inertia will be considered with the subject of acceleration; then motor losses, braking, and regeneration will be taken up; and finally summaries will be made on the energy and power required for train movements.

### POWER UNITS AND FORMULAS.

**Energy and power units,** used in a study of the starting, moving, and stopping of trains, will first be reviewed.

Energy is defined as the ability to perform work; and work is the product of the force and the distance thru which the force acts. Work is measured in results; and is expressed quantitatively, in foot-pounds or in kilowatt-hours.

The unit of energy, in electric traction, is expressed in watt-hours per ton-mile.

Force refers to pull, or pressure. Force is expressed in gravity units, that is, in pounds. The force, R, acting on a train, overcomes gravity, frictional resistance, and inertia.

Speed or velocity is expressed in feet per second, v, or, preferably, in miles per hour, m. p. h.

Power is the *rate* at which work is performed. The mechanical unit is the horse power, 550 foot-pounds per second.

$$\text{Horse power} = \frac{R \times v}{550} = \frac{R \times v \times 5280}{550 \times 3600} = \frac{R \times \text{m. p. h.}}{375.}$$

The electrical unit of power is the kilowatt. 1.34 h. p. = 1.00 kw.

The word power is frequently used in place of the word energy.

**Energy of position** or potential energy is illustrated.

A 1000-ton train at the summit of a grade, which is 4000 feet high, has the ability to perform work in descending a grade, and may even generate energy and deliver it to an electric transmission line and central power station. The amount of energy which, on account of the position of the train, may be generated in descending is

$4000 \times 1000 \times 2000$ or 8,000,000,000 foot-pounds. If the train runs down or up the grade in 2 hours or 7200 seconds, at the rate of 15 m. p. h., the power, or rate of work, excluding the friction averages

8,000,000,000/ 550/ 7200 or 2000 h. p.

The force required in braking the train, if the distance is about 30 miles, or 160,000 feet, averages

$8,000,000,000/160,000 = 50,000$ pounds.

As a check—h. p. $= R \times$ m. p. h.$/375 = 50,000 \times 15/375 = 2000$.

**Energy of motion** of a moving train is, by kinematics, the product of one-half the mass and the square of the velocity. Mass equals weight in pounds divided by 32, the force of gravity. The kinetic energy of motion $= (1/2)MW^2$, or $M_v{}^2/64$, in foot-pounds. Example:

An 870-ton, 25-car train running at 34 m. p. h. (about 50 feet per second) has stored up as kinetic energy

$870 \times 2000 \times 50 \times 50/64$ or 68,000,000 foot-pounds.

If the train is to be stopped within 2000 feet, a retarding force of 34,000 pounds is required, or 39 pounds per ton.

Frictional resistance would be about 7.5 pounds per ton, or 6500 pounds in this example, so that the net retarding force would be 27,500 pounds, or 1100 pounds per car, or 137 pounds per wheel. If the average coefficient of friction is 0.17, the pressure per wheel would be 810 pounds. Master Car Builders' Association rules limit the maximum braking force on the 8 wheels of freight cars to 70 to 90 per cent. of the light weight, to avoid sliding of wheels; or, in the example, about 27,500 pounds.

## POWER FOR TRAINS.

**The power used for electric trains** is a function of:

The weight of the cars hauled.

The speed of the train.

The available tractive coefficient.

The character of the tractive effort.

The tractive resistance or effort per ton, for gravity, friction, and acceleration.

WEIGHT OF CARS, FREIGHT AND PASSENGER, ON RAILROADS.

| Name of cars. | Length in feet. | Type or kind. | Dead weight in tons. | Capacity in tons. |
|---|---|---|---|---|
| Box | 28 to 30 | Wood | 10 to 12 | 20 to 30 |
| Box | 30 to 34 | Wood | 12 to 14 | 25 to 30 |
| Box | 36 | Wood | 15 to 17 | 30 |
| Box | 36 | Wood | 17 to 18 | 40 |
| Box | 36 | Wood | 22 to 23 | 50 |
| Box | 40 | Wood | 17 to 21 | 40 |
| Box | 40 | Wood | 20 to 22 | 50 |
| Box (*C. P. R. R.*) | 36 | Steel | 18 to 20 | 40 |
| Furniture | 30 to 50 | Wood | 17 to 19 | 30 to 40 |
| Stock | 36 | Wood | 14 to 15 | 25 |
| Oil | ........ | Steel | 15 to 18 | 30 to 45 |
| Flat | 28 to 30 | Wood | 9 to 11 | 20 |
| Flat | 32 to 34 | Wood | 10 to 12 | 30 |
| Flat | 40 | Wood | 12 to 13 | 40 |
| Flat | 40 | Steel | 20 to 23 | 50 |
| Coal | ........ | Wood | 12 to 19 | 40 to 50 |
| Coal | ........ | Steel | 16 to 18 | 40 |
| Coal | ........ | Steel | 20 to 22 | 50 to 55 |
| Gondola | ........ | Wood | 12 to 14 | 30 to 40 |
| Gondola | ........ | Steel | 20 | 50 |
| Ore | ........ | Wood | 12 to 13 | 40 to 50 |
| Ore | ........ | Steel | 15 to 20 | 40 to 70 |
| Ballast | ........ | Wood | 12 | 30 to 40 |
| Average, Ry. Age, 1911, p. 935 | ........ | ........ | 19 | 35 |
| Coaches, 8-wheel | 45 to 60 | Wood | 30 to 32 | ........ |
| Coaches, 12-wheel | 50 to 60 | Wood | 35 | ........ |
| Coaches, 12-wheel | 60 to 70 | Steel | 50 to 70 | ........ |
| Mail car | 50 to 70 | Wood | 25 | ........ |
| Mail car | 60 to 70 | Steel | 30 to 45 | ........ |
| Baggage car, 8-wheel | 50 to 60 | Wood | 30 | ........ |
| Baggage car, 12-wheel | 66 | Steel | 72 | ........ |
| Dining car | 50 to 60 | Wood | 40 | ........ |
| Tourist cars | ........ | Wood | 40 | ........ |
| Sleeping cars | 50 to 60 | Wood | 40 to 60 | ........ |
| Sleeping cars | 60 to 70 | Steel | 50 to 65 | ........ |
| Sleepers, Pennsylvania | 60 to 70 | Steel | 60 to 75 | ........ |
| Six-wheel truck only | ........ | Steel | 10 | ........ |
| Buffet Library cars | 72 | Steel | 76 | ........ |
| Pennsylvania R. R., 18-hour, New York-Chicago, six cars | ........ | Steel | 350 | ........ |

American Railway Association's standard freight car has inside dimensions, 36 feet long by 8.5 feet wide by 8 feet high.

European freight cars have four wheels and weigh half as much.

WEIGHT OF MOTOR PASSENGER CARS ON ELECTRIC ROADS.

| Name of cars. | Length in feet. | Type or kind. | Weight in tons. | No. of seats. | Pounds per seat. |
|---|---|---|---|---|---|
| City | 26 to 32 | Wood | 8 to 12 | 28 to 34 | 650 |
| Interurban | 40 | Wood | 20 | 40 | 1000 |
| Interurban | 45 | Wood | 26 | 45 | 1155 |
| Interurban | 50 | Wood | 30 | 50 | 1200 |
| Interurban | 55 | Wood | 36 | 55 | 1310 |
| Interurban | 60 | Wood | 39 | 62 | 1260 |
| Interurban | 60 | Steel | 50 | 64 | 1560 |
| Interurban coach | 60 | Wood | 30 to 45 | 70 | 1070 |
| Rapid Transit | 50 | Wood | 23 to 45 | 55 | 1235 |
| Rapid Transit | 50 | Steel | 35 to 50 | 55 | 1545 |
| Elevated | 45 | Steel | 32 | 48 | 1335 |
| Elevated | 45 | Wood | 28 | 48 | 1165 |
| Tunnel | 50 | Steel | 31 to 38 | 46 to 56 | 1350 |
| Hudson and Manhattan | 48 | Steel | 35 | 44 | 1600 |
| New Haven, motor | 70 | Steel | 87 | 76 | 2290 |
| New Haven, coaches | | Steel | 50 | 76 | 1315 |
| Long Island | 51 | Steel | 38 to 41 | 52 | 1520 |
| Pennsylvania-Long Island | 65 | Steel | 53 | 72 | 1485 |
| West Jersey & Seashore | 55 | Wood | 47 | 58 | 1620 |
| | 55 | Steel | 52 | 58 | 1790 |
| New York Central | 60 | Steel | 54 | 68 | 1590 |
| Southern Pacific suburban | 72 | Steel | 55 | 116 | 950 |
| Midland Ry., England | 60 | Wood | 45 | 72 | 1250 |
| London, Brighton & S. C. | 60 | Steel | 57 | 66 | 1730 |

See complete tabular data on weights of American and European motor cars and coaches, near the end of Chapter VI.

In general, the weight of electric cars is 1400 pounds per seat when arranged for over 60 passengers, and 1000 pounds per seat for 100 or more suburban passengers; an average is about 1200 pounds. For a given number of seats, the weight per seat varies directly with the schedule speed.

Suburban cars, with some side seats, turtle-back roofs, without monitor decks, are not comparable with cars for railroad service.

Steam railroad coaches weigh from 1700 to 2000 pounds per seat.

**References on Weight of Cars.**

Curves showing car weights, E. R. J., Sept. 19, 1908; also October 10, 1908, p. 912.
Standardization suggested, dimensions and drawings, S. R. J., Oct. 15, 1908, p. 1104.
Heron: Relation of Car Length, Weight, Truck Centers, S. R. J., Feb. 8, 1908.
Ayers: Weight and Operating Cost, Amer. Elec. Ry. Assoc., Oct., 1909; E. R. J. Oct. 7, 1909.

SCHEDULE SPEED OF RAILWAY TRAINS.

| Name of railway. | M. p. h. |
|---|---|
| Thru trains, in rolling country | 35 to 40 |
| Local passenger trains | 22 to 28 |
| Mountain freight trains | 5 to 9 |
| Way freight trains | 8 to 12 |
| Time freight trains | 13 to 18 |
| Quick dispatch and refrigerator special | 16 to 18 |
| Stock trains, on prairie divisions | 18 to 22 |
| Fast mail trains, without passengers | 40 to 50 |
| New York Central, 18-hour train, New York-Chicago | 53.5 |
| Pennsylvania R. R., 18-hour train, New York-Chicago | 50.6 |
| Ordinary 24-hour train between New York and Chicago | 40.0 |
| Chicago-Minneapolis passenger trains, 408/13 | 32.0 |
| Minneapolis-Seattle passenger trains, 1814/56 | 32.4 |
| Chicago-Omaha passenger trains, 492/14.6 | 33.7 |
| Chicago-San Francisco passenger trains, 2279/76 | 30.0 |
| New York Subway, local and express | 14 and 30 |
| Manhattan Elevated | 14 to 15 |
| Ordinary street railway | 10 |

SCHEDULE SPEED OF TRAINS INCREASED WITH ELECTRIC TRACTION.

| Name of railway. | Schedule speed. | | Per cent. increase. |
|---|---|---|---|
| | Steam. | Electric. | |
| Brooklyn Rapid Transit | 11.5 | 15.8 | 37 |
| Manhattan Elevated R. R. | 11.0 | 15.0 | 36 |
| Grand Trunk Ry., Port Huron | 6.0 | 10.0 | 66 |
| Metropolitan Elevated, Chicago | 12.0 | 15.0 | 25 |
| South Side Elevated, Chicago | 13.1 | 15.0 | 15 |
| Lake Street Elevated, Chicago | 12.5 | 15.0 | 20 |
| Great Northern Cascade Tunnel | 10.0 | 13.0 | 30 |
| Mersey Ry., England | 15.6 | 19.9 | 27 |
| North-Eastern Ry., England | 16.7 | 20.0 | 20 |
| | 20.1 | 28.2 | 40 |
| Berlin Inner Circle | 11.2 | 15.7 | 40 |
| Milan-Varese R. R. | 18.6 | 27.9 | 50 |
| | 24.8 | 37.2 | 50 |

Number of cars per train was increased 50 to 75 per cent. on the Manhattan; and the number of cars per train on most of the roads listed was increased.

## TRACTIVE COEFFICIENT.

The tractive coefficient, or coefficient of adhesion, is the ratio between the maximum tractive effort and the weight on drivers. It depends largely upon the condition of the rails, and partly on the composition of the steel in contact.

**Coefficients of Friction Between Drivers and Rail:**

| | | |
|---|---|---|
| Most favorable condition | 35%, when sanded | 40% |
| Clean dry rail | 28%, when sanded | 30% |
| Thoroly wet rail | 18%, when sanded | 24% |
| Greasy moist rail | 15%, when sanded | 25% |
| Sleet-covered rail | 15%, when sanded | 20% |
| Dry-snow-covered rail | 11%, when sanded | 15% |

**Character of tractive effort** is involved in tractive coefficient.

Steam locomotives deliver a tractive effort which varies from 28 to 50 per cent. above and below the mean, during each revolution of the driver. The ratio of the *maximum* available tractive effort to adhesive weight on drivers is 25 per cent. This is based on a study made by the Master Mechanics' Association Committee of 1898. Mr. L. H. Fry, in a paper before New York Railroad Club, Sept., 1903, showed as the result of tests on 155 locomotives that the ratio averaged 22 per cent.

Mallet compound steam locomotives lack uniformity of tractive effort from the pistons, during each revolution of the drivers. The two pistons on each side produce efforts on the drivers of independent trucks, which efforts may be exerted in any relation or position from zero to 90 degrees apart.

Electric locomotives deliver a *uniform* tractive effort during the revolution of the drivers. With smooth application of the power by the controller, the tractive effort is from 25 to 35 per cent. of the weight on drivers. However, 22 per cent. is to be recommended as a *basis* in railway service; for, even tho high ratios are *available* with favorable conditions at the rail, they could not be used with bad weather conditions which frequently govern train service.

Electric locomotives sometimes lack uniformity of tractive effort during train acceleration. This is caused by the opening of the circuits in some types of series-parallel, or concatenated controllers; or change in the number of poles, or crude schemes which require that power be shut off to change the motor combinations. The cutting in and out of large blocks of resistance causes jerking of the train, but this can be obviated by connecting more taps to the resistances or transformer. Water rheostats which make gradual changes in the resistance, a scheme used on Field's locomotives in 1883, are used on some European work.

Motor-car trains, even in bad weather and without the use of sand under the wheels, have ample and uniform tractive effort. The acceleration rate may be high because so much of the weight is on the drivers.

Tractive effort to overcome train resistance and inertia is thus limited by the coefficient of adhesion or condition of the rail, the uniformity of tractive effort, and the amount and distribution of weight. The method of suspension of the motors on the truck also affects the maximum tractive effort. See Eaton: Electric Journal, Dec., 1910.

## TRACTIVE RESISTANCE.

Tractive resistance to motion is caused by gravity, friction of the train, including bearings, rails, curves, air resistance, and inertia.

## GRADES.

Grades increase the tractive effort required per ton. Each 1 per cent. grade increases the pull or lift 1 per cent. of 2000 pounds, or 20 pounds per ton, and this is to be added to the frictional resistance and to the accelerating resistance per ton.

## FRICTIONAL RESISTANCE.

Resistance measurements with dynamometer cars are faulty because they do not include the head-end resistance of the locomotive or of the leading motor car. Results from electric meters include head-end friction, mechanical friction, and electric motor losses. Results derived from indicator cards of steam locomotives are also correct.

**Train friction equations** are of the form $R = A + BV + CV^2$, wherein R is the total resistance to motion, in pounds per ton; V the velocity of the train, plus or minus the velocity of the wind, in m. p. h.

$A$ stands for journal friction, which increases slightly with the speed and varies inversely as the square root of the pressure on the journals. Friction per ton is much greater with empty than with loaded cars; it varies greatly with the quantity and quality of the lubricant, and with the temperature. It includes friction of motor bearings, brushes on commutators, friction of machinery, trucks, spring oscillation, etc.

$B$ stands for rail friction, which varies with the diameter of the wheels, length of wheel base, cleanliness, dryness and stiffness of rails, the track sol dity or inelasticity, and the flange friction between wheels and rails caused by concussions and by side winds. Oscillations, concussions, and waves in rails occur on poor track and cause extra resistance to motion.

$C$ stands for wind or air resistance, and varies with the shape or contour of the front and rear vestibules, sides, surfaces, cross-section of the locomotive and cars, and the number of cars, N, in the train.

The numerical values of the constants, A, B, and C, in pounds are:

$A = 3.0$ for 70-ton freight cars; 6.0 for empty freight cars; 4.0 for passenger coaches and light loaded freight cars; 4.0 for 45-ton, 4.5 for 35-ton, and 5 to 6 for 25- to 15-ton passenger or freight cars.

$B = 0.06$ for excellent track; 0.11 for heavy track; 0.10 up to 0.15 for ordinary good track. Data on freight cars indicate that $B = .05$.

$C$ is a variable quantity which depends on the shape of the front of the train, K, and the effective cross-sectional area of the train in square feet, divided by the total weight of the train. C = K x Area/Tons. The values of K, in pounds per square foot, are:
.0010 for parabolic fronts; .0040 for flat fronts; .0020 for wedged fronts; .0028 for vestibule cars; .0030 for open platforms; .0033 for freight cars; and higher values for open-end coaches and small electric cars.

Cross-sectional areas are about 85 square feet for a street car; 100 for an interurban car; 120 for a locomotive or a coach; 120 to 140 for a freight car. To the above, 10 per cent. of the cross-sectional area is added for each trailing car.

FRICTIONAL RESISTANCE OF TRAINS IN GENERAL.

$$R = A + BV + K \times Area \times \frac{V^2}{T}$$

$$R = \begin{Bmatrix} 3.0 \\ 3.5 \\ 4.0 \\ 5.0 \\ 6.0 \end{Bmatrix} + \begin{Bmatrix} .05 \\ .10 \\ .11xV \\ .12 \\ .15 \end{Bmatrix} + \begin{Bmatrix} .0020 \\ .0028 \\ .0030 \\ .0033 \\ .0040 \end{Bmatrix} \times \begin{Bmatrix} 85 \\ 100 \\ 110x(1+.10(N-1))x\frac{V^2}{T} \\ 120 \\ 140 \end{Bmatrix}$$

TRACTIVE RESISTANCE FORMULAS FOR TRAINS.

| Authority. | Value of R—Tractive resistance. | Notes on service. |
|---|---|---|
| Baldwin | $3.0+.166V$ | Steam trains. |
| Eng. News | $2.0+.250V$ | General use. |
| Dudley | $3.5+.150V+(.02\ N-25)V^2/T$ | Long trains. |
| Lundie | $4.0+.200V+\ .48V^2/T$ | Elevated railways. |
| Blood | $5.0+.120V+(.0014+.35/T)V^{1.8}$ | Motor-car trains. |
| Sprague | $4.0+.160V+\ .333V^2/T$ | General use. |
| Davis, W. J. | $4.0+.130V+(.0040AV^2/T)\ (1+.1\ (N-1))$ | Electric trains. |
| Smith, W. N. | $4.0+.167V+\ .0025AV^2/T$ | Suburban service. |
| Mailloux | $3.5+.150V+(.020\ N+0.25)V^2/T$ | Motor-car trains. |
| Armstrong | $\frac{5.0}{\sqrt{T}}+.030V+(.0020AV^2/T)\ (1+.1(N-1))$ | Short trains. |

Value of R for Freight Trains, Exclusive of Locomotive.

| | | |
|---|---|---|
| Dennis | $2.41\ T+\ 90\ N$ | Average of tests, 1904. |
| Onderonk | $2.78\ T+114\ N$ | Baltimore & Ohio test, 1904. |
| Cole | $1.07\ T+138\ N$ | Penn. R. R. tests, 1907. |
| Amer. Ry. Eng. Association | $2.22\ T+122\ N$ | Recommendation, 1910. |
| | | N = no. of cars per train. |

The last four formulas assume that, between 5 and 30 m.p.h., the friction is independent of the velocity. It is well to point out that there is nothing in data of tests to support this assumption. Conclusive tests show an increase of 50 per cent. between 5 and 30 m.p.h.

**Value of R for Steam Locomotives** recommended by the American Railway Engineering Association for the friction between the cylinder and the rim of the drivers is $R = 18.7\ T + 80X$, where $T$ = tons on drivers, and $X$ = number of driving axles.

American Locomotive Company's tests show that the mechanical friction resistance of the engine without tender is equal to the weight on drivers in tons x 22.2 pounds.

**Values of Air Resistance Constant, C, in pounds, as detailed by Goss:**

$C = .240V^2$ for locomotive $= .002V^2 x A$, where $A = 120$ square feet.
$C = .110V^2$ for locomotive and tender.
$C = .026V^2$ for last car of a freight train.
$C = .036V^2$ for last car of passenger train.
$C = .010V^2$ for each intermediate freight car.
$C = .020V^2$ for each intermediate passenger car.

## FRICTIONAL RESISTANCE TABLES.

The application of train friction constants to motor-car trains is shown in the following Tables on Tractive Resistance. They have been checked repeatedly for ordinary conditions, on a private right-of-way. The variable which requires the most consideration is B.

### TRACTIVE RESISTANCE—SINGLE-CAR OPERATION.

| | | |
|---|---|---|
| 15-ton car | | $R = 6.0 + .11V + .30xV^2\ (1 + 0.1\ (N - 1)/T)$ |
| | 10 m. p. h., | $R = 6.0 + 1.1 + .30x\ 100/15 = 6.0 + 1.1 + 2.0 = 9.1$ |
| | 20 | $6.0 + 2.2 + .30x\ 400/15 = 6.0 + 2.2 + 8.0 = 16.2$ |
| | 30 | $6.0 + 3.3 + .30x\ 900/15 = 6.0 + 3.3 + 18.0 = 27.3$ |
| | 40 | $6.0 + 4.4 + .30x1600/15 = 6.0 + 4.4 + 32.0 = 42.4$ |
| | 50 | $6.0 + 5.5 + .30x2500/15 = 6.0 + 5.5 + 50.0 = 61.5$ |
| | 60 | $6.0 + 6.6 + .30x3600/15 = 6.0 + 6.6 + 72.0 = 84.6$ |
| 20-ton car | | $R = 5.5 + .12V + .30xV^2\ (1 + 0.1\ (N-1))/T$ |
| | 10 m. p. h., | $R = 5.5 + 1.2 + .30x\ 100/20 = 5.5 + 1.2 + 1.5 = 8.2$ |
| | 20 | $5.5 + 2.4 + .30x\ 400/20 = 5.5 + 2.4 + 6.0 = 13.9$ |
| | 30 | $5.5 + 3.6 + .30x\ 900/20 = 5.5 + 3.6 + 13.5 = 22.6$ |
| | 40 | $5.5 + 4.8 + .30x1600/20 = 5.5 + 4.8 + 24.0 = 34.3$ |
| | 50 | $5.5 + 6.0 + .30x2500/20 = 5.5 + 6.0 + 37.5 = 49.0$ |
| | 60 | $5.5 + 7.2 + .30x3600/20 = 5.5 + 7.2 + 54.0 = 66.7$ |
| 25-ton car | | $R = 5.0 + .13V + .30xV^2\ (1 + 0.1\ (N - 1))/T.$ |
| | 10 m. p. h., | $R = 5.0 + 1.3 + .30x\ 100/25 = 5.0 + 1.3 + 1.2 = 7.5$ |
| | 20 | $5.0 + 2.6 + .30x\ 400/25 = 5.0 + 2.6 + 4.8 = 12.4$ |
| | 30 | $5.0 + 3.9 + .30x\ 900/25 = 5.0 + 3.9 + 10.8 = 19.7$ |
| | 40 | $5.0 + 5.2 + .30x1600/25 = 5.0 + 5.2 + 19.2 = 29.4$ |
| | 50 | $5.0 + 6.5 + .30x2500/25 = 5.0 + 6.5 + 30.0 = 41.5$ |

35-ton car . . . . . . . . . . . . . . . . . $R = 4.5 + .13V + .30xV^2 (1 + 0.1 (N - 1))/T$

| | |
|---|---|
| 10 m. p. h., | R = 4.5 + 1.3 + .30x 100/35 = 4.5 + 1.3 + 0.9 = 6.7 |
| 20 | 4.5 + 2.6 + .30x 400/35 = 4.5 + 2.6 + 3.4 = 10.5 |
| 30 | 4.5 + 3.9 + .30x 900/35 = 4.5 + 3.9 + 7.7 = 16.1 |
| 40 | 4.5 + 5.2 + .30x1600/35 = 4.5 + 5.2 + 13.7 = 23.4 |
| 50 | 4.5 + 6.5 + .30x2500/35 = 4.5 + 6.5 + 21.4 = 32.4 |

45-ton car . . . . . . . . . . . . . . . . . $R = 4.0 + .13V + .33xV^2 (1 + 0.1 (N - 1))/T$

| | |
|---|---|
| 10 m. p. h., | R = 4.0 + 1.3 + .33x 100/45 = 4.0 + 1.3 + 0.7 = 6.0 |
| 20 | 4.0 + 2.6 + .33x 400/45 = 4.0 + 2.6 + 3.0 = 9.6 |
| 30 | 4.0 + 3.9 + .33x 900/45 = 4.0 + 3.9 + 6.6 = 14.5 |
| 40 | 4.0 + 5.2 + .33x1600/45 = 4.0 + 5.2 + 12.0 = 21.2 |
| 50 | 4.0 + 6.5 + .33x2500/45 = 4.0 + 6.5 + 18.3 = 28.8 |

## TRACTIVE RESISTANCE—2-CAR TRAIN.

15-ton cars . . . . . . . . . . . . . $R = 6.0 + .11V + .30xV^2 (1 + 0.1 (N - 1))/T$

| | |
|---|---|
| 10 m. p. h., | R = 6.0 + 1.1 + .30x 100x1.1/30 = 6.0 + 1.1 + 1.1 = 8.2 |
| 20 | 6.0 + 2.2 + .30x 400x1.1/30 = 6.0 + 2.2 + 4.4 = 12.6 |
| 30 | 6.0 + 3.3 + .30x 900x1.1/30 = 6.0 + 3.3 + 9.9 = 19.2 |
| 40 | 6.0 + 4.4 + .30x1600x1.1/30 = 6.0 + 4.4 + 17.6 = 28.0 |
| 50 | 6.0 + 5.5 + .30x2500x1.1/30 = 6.0 + 5.5 + 27.5 = 39.0 |
| 60 | 6.0 + 6.6 + .30x3600x1.1/30 = 6.0 + 6.6 + 39.6 = 52.2 |

20-ton cars . . . . . . . . . . . . . $R = 5.5 + .12V + .30xV^2x1.1/T$

| | |
|---|---|
| 10 m. p. h., | R = 5.5 + 1.2 + .30x 100x1.1/40 = 5.5 + 1.2 + 0.8 = 7.5 |
| 20 | 5.5 + 2.4 + .30x 400x1.1/40 = 5.5 + 2.4 + 3.3 = 11.2 |
| 30 | 5.5 + 3.6 + .30x 900x1.1/40 = 5.5 + 3.6 + 7.4 = 16.5 |
| 40 | 5.5 + 4.8 + .30x1600x1.1/40 = 5.5 + 4.8 + 13.2 = 23.5 |
| 50 | 5.5 + 6.0 + .30x2500x1.1/40 = 5.5 + 6.0 + 20.6 = 32.1 |
| 60 | 5.5 + 7.2 + .30x3600x1.1/40 = 5.5 + 7.2 + 29.7 = 42.4 |

25-ton cars . . . . . . . . . . . . . $R = 5.0 + .13V + .30xV^2x1.1/T$

| | |
|---|---|
| 10 m. p. h., | R = 5.0 + 1.3 + .30x 100x1.1/50 = 5.0 + 1.3 + 0.7 = 7.0 |
| 20 | 5.0 + 2.6 + .30x 400x1.1/50 = 5.0 + 2.6 + 2.6 = 10.2 |
| 30 | 5.0 + 3.9 + .30x 900x1.1/50 = 5.0 + 3.9 + 5.9 = 14.8 |
| 40 | 5.0 + 5.2 + .30x1600x1.1/50 = 5.0 + 5.2 + 10.6 = 20.8 |
| 50 | 5.0 + 6.5 + .30x2500x1.1/50 = 5.0 + 6.5 + 16.5 = 28.0 |
| 60 | 5.0 + 7.8 + .30x3600x1.1/50 = 5.0 + 7.8 + 23.7 = 36.5 |

35-ton cars . . . . . . . . . . . . . $R = 4.5 + .13V + .30xV^2x1.1/T$

| | |
|---|---|
| 10 m. p. h., | R = 4.5 + 1.3 + .30x 100x1.1/70 = 4.5 + 1.3 + 0.5 = 6.3 |
| 20 | 4.5 + 2.6 + .30x 400x1.1/70 = 4.5 + 2.6 + 1.9 = 9.0 |
| 30 | 4.5 + 3.9 + .30x 900x1.1/70 = 4.5 + 3.9 + 4.2 = 12.6 |
| 40 | 4.5 + 5.2 + .30x1600x1.1/70 = 4.5 + 5.2 + 7.5 = 17.2 |
| 50 | 4.5 + 6.5 + .30x2500x1.1/70 = 4.5 + 6.5 + 11.8 = 22.8 |
| 60 | 4.5 + 7.8 + .30x3600x1.1/70 = 4.5 + 7.8 + 17.0 = 29.3 |

45-ton cars . . . . . . . . . . . . . $R = 4.0 + .13V + .33xV^2x1.1/T$

| | |
|---|---|
| 10 m. p. h., | R = 4.0 + 1.3 + .33x 100x1.1/90 = 4.0 + 1.3 + 0.4 = 5.7 |
| 20 | 4.0 + 2.6 + .33x 400x1.1/90 = 4.0 + 2.6 + 1.6 = 8.2 |
| 30 | 4.0 + 3.9 + .33x 900x1.1/90 = 4.0 + 3.9 + 3.6 = 11.5 |
| 40 | 4.0 + 5.2 + .33x1600x1.1/90 = 4.0 + 5.2 + 6.4 = 15.6 |
| 50 | 4.0 + 6.5 + .33x2500x1.1/90 = 4.0 + 6.5 + 10.0 = 20.5 |
| 60 | 4.0 + 7.8 + .33x3600x1.1/90 = 4.0 + 7.8 + 14.5 = 26.3 |

## TRACTIVE RESISTANCE—3-CAR TRAIN.

15-ton car . . . . . . . . . . . . . . R=6.0+.11V+.30x$V^2$ (1+0.1 (N–1))/T

10 m. p. h., R=6.0+1.1+.30x 100x1.2/45=6.0+1.1+ .8= 7.9
20 6.0+2.2+.30x 400x1.2/45=6.0+2.2+ 3.2=11.4
30 6.0+3.3+.30x 900x1.2/45=6.0+3.3+ 7.2=16.5
40 6.0+4.4+.30x1600x1.2/45=6.0+4.4+12.8=23.2
50 6.0+5.5+.30x2500x1.2/45=6.0+5.5+20.0=31.5
60 6.0+6.6+.30x3600x1.2/45=6.0+6.6+28.8=41.4

20-ton car . . . . . . . . . . . . . . R=5.5+.12V+.30x$V^2$x1.2/T

10 m. p. h., R=5.5+1.2+.30x 100x1.2/60=5.5+1.2+ .6= 7.3
20 5.5+2.4+.30x 400x1.2/60=5.5+2.4+ 2.4=10.3
30 5.5+3.6+.30x 900x1.2/60=5.5+3.6+ 5.4=14.5
40 5.5+4.8+.30x1600x1.2/60=5.5+4.8+ 9.6=19.9
50 5.5+6.0+.30x2500x1.2/60=5.5+6.0+15.0=26.5
60 5.5+7.2+.30x3600x1.2/60=5.5+7.2+21.6=34.3

25-ton car . . . . . . . . . . . . . . R=5.0+.13V+.30x$V^2$x1.2/T

10 m. p. h., R=5.0+1.3+.30x 100x1.2/75=5.0+1.3+ .5= 6.8
20 5.0+2.6+.30x 400x1.2/75=5.0+2.6+ 1.9= 9.5
30 5.0+3.9+.30x 900x1.2/75=5.0+3.9+ 4.3=13.2
40 5.0+5.2+.30x1600x1.2/75=5.0+5.2+ 7.7=17.9
50 5.0+6.5+.30x2500x1.2/75=5.0+6.5+12.2=23.7
60 5.0+7.8+.30x3600x1.2/75=5.0+7.8+17.3=30.1

30-ton car . . . . . . . . . . . . . . R=4.5+.13V+.30x$V^2$x1.2/T

10 m. p. h., R=4.5+1.3+.30x 100x1.2/90=4.5+1.3= .4= 6.2
20 4.5+2.6+.30x 400x1.2/90=4.5+2.6+ 1.6= 8.7
30 4.5+3.9+.30x 900x1.2/90=4.5+3.9+ 3.6=12.0
40 4.5+5.2+.30x1600x1.2/90=4.5+5.2+ 6.4=16.1
50 4.5+6.5+.30x2500x1.2/90=4.5+6.5+10.0=21.0
60 4.5+7.8+.30x3600x1.2/90=4.5+7.8+14.4=26.7

35-ton car . . . . . . . . . . . . . . R=4.5+.13V+.30x1$V^2$x.2/T

10 m. p. h., R=4.5+1.3+.30x 100x1.2/105=4.5+1.3+ .3= 6.1
20 4.5+2.6+.30x 400x1.2/105=4.5+2.6+ 1.4= 8.5
30 4.5+3.9+.30x 900x1.2/105=4.5+3.9+ 3.0=11.4
40 4.5+5.2+.30x1600x1.2/105=4.5+5.2+ 5.5=15.2
50 4.5+6.5+.30x2500x1.2/105=4.5+6.5+ 8.6=19.6
60 4.5+7.8+.30x3600x1.2/105=4.5+7.8+12.3=24.6

45-ton car . . . . . . . . . . . . . . R=4.0+.13V+.33x$V^2$x1.2/T

10 m. p. h., R=4.0+1.3+.33x 100x1.2/135=4.0+1.3+ .3= 5.6
20 4.0+2.6+.33x 400x1.2/135=4.0+2.6+ 1.2= 7.8
30 4.0+3.9+.33x 900x1.2/135=4.0+3.9+ 2.6=10.5
40 4.0+5.2+.33x1600x1.2/135=4.0+5.2+ 4.7=13.9
50 4.0+6.5+.33x2500x1.2/135=4.0+6.5+ 7.3=17.8
60 4.0+7.8+.33x3600x1.2/135=4.0+7.8+10.6=22.4

## TRACTIVE RESISTANCE—4-CAR TRAIN.

25-ton cars . . . . . . . . . . . . $R=5.0+.13V+.30V^2\ (1+0.1\ (N-1))/T$

| | |
|---|---|
| 10 m. p. h., | R=5.0+1.3+.30x 100x1.3/100=5.0+1.3+ 0.4= 6.7 |
| 20 | 5.0+2.6+.30x 400x1.3/100=5.0+2.6+ 1.6= 9.2 |
| 30 | 5.0+3.9+.30x 900x1.3/100=5.0+3.9+ 3.5=12.4 |
| 40 | 5.0+5.2+.30x1600x1.3/100=5.0+5.2+ 6.2=16.4 |
| 50 | 5.0+6.5+.30x2500x1.3/100=5.0+6.5+ 9.8=21.3 |
| 60 | 5.0+7.8+.30x3600x1.3/100=5.0+7.8+14.0=26.8 |

30-ton cars . . . . . . . . . . . . $R=4.5+.13V+.30xV^2x1.3/120$

| | |
|---|---|
| 10 m. p. h., | 4.5+1.3+.30x 100x1.3/120=4.5+1.3+ 0.3= 6.1 |
| 20 | 4.5+2.6+.30x 400x1.3/120=4.5+2.6+ 1.3= 8.4 |
| 30 | 4.5+3.9+.30x 900x1.3/120=4.5+3.9+ 2.9=11.3 |
| 40 | 4.5+5.2+.30x1600x1.3/120=4.5+5.2+ 5.2=14.9 |
| 50 | 4.5+6.5+.30x2500x1.3/120=4.5+6.5+ 8.1=19.1 |
| 60 | 4.5+7.8+.30x3600x1.3/120=4.5+7.8+11.7=24.0 |

35-ton cars . . . . . . . . . . . . $R=4.5+.13V+.30xV^2x1.3/140$

| | |
|---|---|
| 10 m. p. h., | 4.5+1.3+.30x 100x1.3/140=4.5+1.3+ 0.3= 6.1 |
| 20 | 4.5+2.6+.30x 400x1.3/140=4.5+2.6+ 1.1= 8.2 |
| 30 | 4.5+3.9+.30x 900x1.3/140=4.5+3.9+ 2.5=10.9 |
| 40 | 4.5+5.2+.30x1600x1.3/140=4.5+5.2+ 4.4=14.1 |
| 50 | 4.5+6.5+.30x2500x1.3/140=4.5+6.5+ 7.0=18.0 |
| 60 | 4.5+7.8+.30x3600x1.3/140=4.5+7.8+10.0=22.3 |

45-ton cars. . . . . . . . . . . . $R=4.0+.13\ V+.33xV^2x1.3/180$

| | |
|---|---|
| 10 m. p. h., | 4.0+1.3+.33x 100x1.3/180=4.0+1.3+ 0.2= 5.5 |
| 20 | 4.0+2.6+.33x 400x1.3/180=4.0+2.6+ 1.0= 7.6 |
| 30 | 4.0+3.9+.33x 900x1.3/180=4.0+3.9+ 2.1=10.0 |
| 40 | 4.0+5.2+.33x1600x1.3/180=4.0+5.2+ 3.8=13.0 |
| 50 | 4.0+6.5+.33x2500x1.3/180=4.0+6.5+ 6.0=16.5 |
| 60 | 4.0+7.8+.33x3600x1.3/180=4.0+7.8+ 8.6=20.4 |

## TRACTIVE RESISTANCE—6-CAR TRAIN.

25-ton cars . . . . . . . . . . . . $R=5.0+.13V+.30xV^2\ (1+0.10\ (N-1))1/T$

| | |
|---|---|
| 10 m. p. h., | R=5.0+1.3+.30x 100x1.5/150=5.0+1.3+ 0.3= 6.6 |
| 20 | 5.0+2.6+.30x 400x1.5/150=5.0+2.6+ 1.2= 8.8 |
| 30 | 5.0+3.9+.30x 900x1.5/150=5.0+3.9+ 2.7=11.6 |
| 40 | 5.0+5.2+.30x1600x1.5/150=5.0+5.2+ 4.8=15.0 |
| 50 | 5.0+6.5+.30x2500x1.5/150=5.0+6.5+ 7.5=19.0 |
| 60 | 5.0+7.8+.30x3600x1.5/150=5.0+7.8+10.8=23.6 |

35-ton cars . . . . . . . . . . . . $R=4.5+.13V+.30xV^2x1.5/T$

| | |
|---|---|
| 10 m. p. h., | R=4.5+1.3+.30x 100x1.5/210=4.5+1.3+ 0.2= 6.0 |
| 20 | 4.5+2.6+.30x 400x1.5/210=4.5+2.6+ 0.9= 8.0 |
| 30 | 4.5+3.9+.30x 900x1.5/210=4.5+3.9+ 1.9=10.3 |
| 40 | 4.5+5.2+.30x1600x1.5/210=4.5+5.2+ 3.4=13.1 |
| 50 | 4.5+6.5+.30x2500x1.5/210=4.5+6.5+ 5.4=16.4 |
| 60 | 4.5+7.8+.30x3600x1.5/210=4.5+7.8+ 7.7=20.0 |

45-ton cars.............R=4.0+.13V + .33xV²x1.5/T

| | | |
|---|---|---|
| 10 m. p. h., | R=4.0+1.3+.33x 100x1.5/270=4.0+1.3+ .2= 5.5 | |
| 20 | 4.0+2.6+.33x 400x1.5/270=4.0+2.6+ .7= 7.3 | |
| 30 | 4.0+3.9+.33x 900x1.5/270=4.0+3.9+ 1.6= 9.5 | |
| 40 | 4.0+5.2+.33x1600x1.5/270=4.0+5.2+ 2.9=12.1 | |
| 50 | 4.0+6.5+.33x2500x1.5/270=4.0+6.5+ 4.6=15.1 | |
| 60 | 4.0+7.8+.33x3600x1.5/270=4.0+7.8+ 6.6=18.4 | |

## TRACTIVE RESISTANCE—8-CAR PASSENGER TRAIN.

35-ton car............R=4.5+.13V+.30xV² (1+0.1 (N−1))/T

| | |
|---|---|
| 10 m. p. h., | R=4.5+1.3+.30x 100x1.7/280=4.5+1.3+ .17 =6.0 |
| 20 | 4.5+2.6+.30x 400x1.7/280=4.5+2.6+ .71= 7.8 |
| 30 | 4.5+3.9+.30x 900x1.7/280=4.5+3.9+1.63=10.0 |
| 40 | 4.5+5.2+.30x1600x1.7/280=4.5+5.2+2.89=12.5 |
| 50 | 4.5+6.5+.30x2500x1.7/280=4.5+6.5+4.53=15.5 |

45-ton car..............R=4.0+.13V+.33xV² (1.+0.1 (N−1))/T

| | |
|---|---|
| 10 m. p. h., | R=4.0+1.3+.33x 100x1.7/360=4.0+1.3+ .15= 5.4 |
| 20 | 4.0+2.6+.33x 400x1.7/360=4.0+2.6+ .62= 7.2 |
| 30 | 4.0+3.9+.33x 900x1.7/360=4.0+3.9+1.36= 9.2 |
| 40 | 4.0+5.2+.33x1600x1.7/360=4.0+5.2+2.47=11.7 |
| 50 | 4.0+6.5+.33x2500x1.7/360=4.0+6.5+3.89=14.4 |

## TRACTIVE RESISTANCE—12-CAR PASSENGER TRAIN.

45-ton car .............R=4.0+.13V+.33xV² (1+0.1 (N−1))/T

| | |
|---|---|
| 10 m. p. h., | R=4.0+1.3+.33x 100x2.1/540=4.0+1.3+ .12= 5.4 |
| 20 | 4.0+2.6+.33x 400x2.1/540=4.0+2.6+ .43= 7.0 |
| 30 | 4.0+3.9+.33x 900x2.1/540=4.0+3.9+1.15= 9.0 |
| 40 | 4.0+5.2+.33x1600x2.1/540=4.0+5.2+2.03=11.2 |
| 50 | 4.0+6.5+.33x2500x2.1/540=4.0+6.5+3.19=13.7 |
| 60 | 4.0+7.8+.33x3600x2.1/540=4.0+7.8+4.62=16.4 |

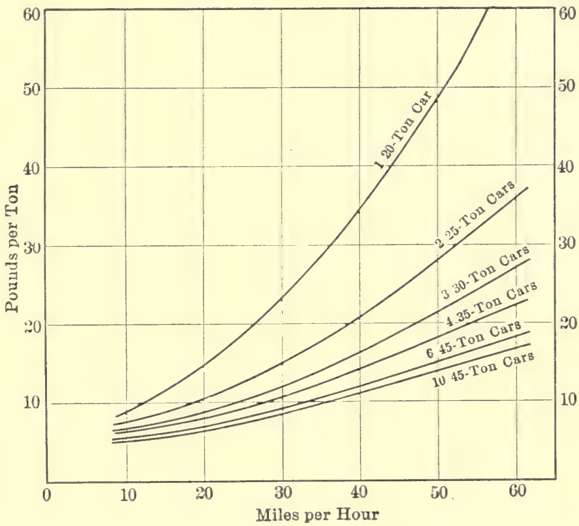


FIG. 167.—TRACTIVE RESISTANCE CURVES.
One to ten electric motor-car passenger trains.

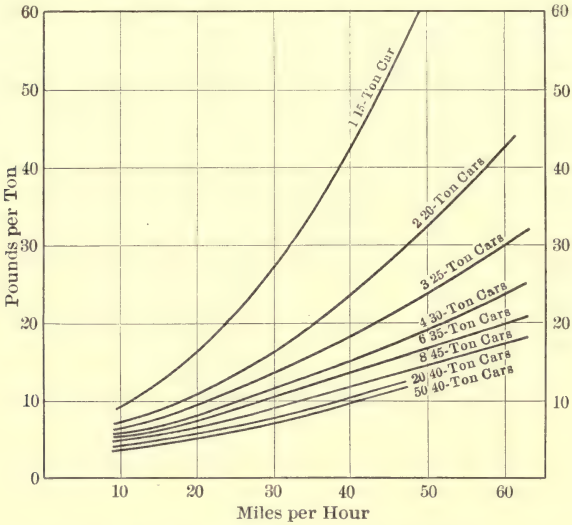


FIG. 168.—TRACTIVE RESISTANCE CURVES.
One to eight electric motor-car passenger trains, also 20 to 50-car electric locomotive hauled freight trains.

**New York Central trains** on the "Twentieth Century Limited" with 63-ton Pullman coaches and Pacific type steam locomotives (see page 66) show that the tractive resistance on level tangents is as follows:

| Speed, m. p. h. | Cars in train. | Wt. of cars, tons. | Wt. of loco., tons. | Friction per ton, cars. | Friction per ton, loco. | Friction per ton, total. |
|---|---|---|---|---|---|---|
| 70 | 5 | 315 | 200 | 11.5 | 22.7 | 15.9 |
| 62 | 8 | 505 | 200 | 9.8 | 20.3 | 12.9 |
| 60 | 9 | 564 | 200 | 9.5 | 19.7 | 12.2 |

TRACTIVE RESISTANCE OF FREIGHT CARS IN TRAINS.

10 cars. 300-ton load. $R = 5.0 + .06V + .33xV^2\ (1 + 0.1\ (N-1))/T$

| | | |
|---|---|---|
| 10 m. p. h., | $R = 5.0 + 0.6 + .33x\ 100x1.9/300 = 5.0 + 0.6 + 0.2 =$ | 5.8 |
| 20 | $5.0 + 1.2 + .33x\ 400x1.9/300 = 5.0 + 1.2 + 0.8 =$ | 7.0 |
| 30 | $5.0 + 1.8 + .33x\ 900x1.9/300 = 5.0 + 1.8 + 1.9 =$ | 8.7 |
| 40 | $5.0 + 2.4 + .33x1600x1.9/300 = 5.0 + 2.4 + 3.3 =$ | 10.7 |

20 cars. 600-ton load. $R = 5.0 + .06V + .33xV^2\ (1 + 0.1\ (N-1))/T$

| | | |
|---|---|---|
| 10 m. p. h., | $R = 5.0 + 0.6 + .33x\ 100x2.9/600 = 5.0 + 0.6 + 0.1 =$ | 5.7 |
| 20 | $5.0 + 1.2 + .33x\ 400x2.9/600 = 5.0 + 1.2 + 0.6 =$ | 6.8 |
| 30 | $5.0 + 1.8 + .33x\ 900x2.9/600 = 5.0 + 1.8 + 1.4 =$ | 8.2 |
| 40 | $5.0 + 2.4 + .33x1600x2.9/600 = 5.0 + 2.4 + 2.5 =$ | 9.9 |

| | | |
|---|---|---|
| 30 cars. | 1200-ton load. | $R = 4.0 + .06V + .33 x V^2 (1 + 0.1 (N-1))/T$ |
| | 10 m. p. h., | $R = 4.0 + 0.6 + .33 x\ 100 x 3.9/1200 = 4.0 + 0.6 + 0.1 = 4.7$ |
| | 20 | $4.0 + 1.2 + .33 x\ 400 x 3.9/1200 = 4.0 + 1.2 + 0.4 = 5.6$ |
| | 30 | $4.0 + 1.8 + .33 x\ 900 x 3.9/1200 = 4.0 + 1.8 + 0.9 = 6.7$ |
| | 40 | $4.0 + 2.4 + .33 x 1600 x 3.9/1200 = 4.0 + 2.4 + 1.7 = 8.1$ |
| 50 cars. | 2000-ton load. | $R = 4.0 + .06V + .33 x V^2 (1 + 0.1 (N-1))/T$ |
| | 10 m. p. h., | $R = 4.0 + 0.6 + .33 x\ 100 x 5.9/2000 = 4.0 + 0.6 + 0.1 = 4.7$ |
| | 20 | $4.0 + 1.2 + .33 x\ 400 x 5.9/2000 = 4.0 + 1.2 + 0.4 = 5.6$ |
| | 30 | $4.0 + 1.8 + .33 x\ 900 x 5.9/2000 = 4.0 + 1.8 + 0.9 = 6.7$ |
| | 40 | $4.0 + 2.4 + .33 x 1600 x 5.9/2000 = 4.0 + 2.4 + 1.6 = 8.0$ |
| 40 cars. | 2000-ton load. | $R = 3.5 + .06V + .33 x V^2 (1 + 0.1(N-1))/T$ |
| | 10 m. p. h., | $R = 3.5 + 0.6 + .33 x\ 100 x 4.9/2000 = 3.5 + 0.6 + 0.1 = 4.2$ |
| | 20 | $3.5 + 1.2 + .33 x\ 400 x 4.9/2000 = 3.5 + 1.2 + 0.3 = 5.0$ |
| | 30 | $3.5 + 1.8 + .33 x\ 900 x 4.9/2000 = 3.5 + 1.8 + 0.7 = 6.0$ |
| | 40 | $3.5 + 2.4 + .33 x 1600 x 4.9/2000 = 3.5 + 2.4 + 1.3 = 7.2$ |

Tractive resistance in pounds for the electric or steam locomotive is to be added, viz.: $22.2 \times$ tons on drivers for locomotive friction; and $0.24V^2$ for locomotive head air resistance. Count the tender, if a steam locomotive is used, as one car.

See data from N. Y. N. H. & H. electric locomotive tests, page 429.

**Winter weather** will often cause an increase of 60 per cent., over the resistance given above, which is for ordinary summer weather on ordinary good track.

## CURVES.

Curve resistance has been found to vary from 0.56 to 0.70, but to average 0.60 pounds, per ton per degree of curvature. Steam railroads use the rule, 0.7 pounds per ton for the train and 1.6 pounds per ton for the engine, per degree of curvature. The number of degrees equals 5730 divided by the radius of the curve in feet.

Reverse curves are frequent in rough country. Where grades are equated for curvature, it is sufficient to use the resistance due to the grade. When the train is of great length engines are sometimes stalled on level track by the reverse curves alone.

## INERTIA.

Inertia requires the application of force to produce motion, and generally the force required is many times greater than that to simply overcome friction. The tractive effort required to overcome inertia depends upon the rate of change of speed, or the acceleration, which is to be produced.

The unit of acceleration is the change in speed per mile per hour per second. One m. p. h. p. s. = 1.466 feet per second per second.

## ACCELERATION RATES COMMONLY USED FOR TRAINS.

| | | |
|---|---|---|
| Steam locomotive, | long and way freight | .1 to .2 |
| Steam locomotive, | common passenger trains | .2 to .5 |
| Steam locomotive, | transcontinental passenger trains | .1 to .3 |
| Electric locomotives, | common freight service | .1 to .3 |
| Electric locomotives, | thru passenger trains | .2 to .6 |
| Electric locomotives, | local passenger trains | .4 to .6 |
| Electric motor cars, | interurban service | .8 to 1.3 |
| Electric motor cars, | city cars | 1.3 to 1.6 |
| Electric motor cars, | rapid transit trains | 1.3 to 1.8 |
| Electric motor cars, | highest rates | 2.0 to 2.5 |
| Maximum rate used, | coefficient of friction x 32.2 | 6.0 to 8.0 |

## ACCELERATING RATES OF ELECTRIC RAILWAY TRAINS.

| Name of electric railroad. | Initial rate m.p.h.p.s. | Rate to half-speed m.p.h.p.s. | Cars per train. | Tons per train. | H. p. per train. | H. p. per ton. |
|---|---|---|---|---|---|---|
| Boston Elevated | 1.24 | 1.00 | 6 | 210 | 2100 | 10.00 |
| Boston & Worcester | 1.57 | 1.50 | 1 | 25 | 200 | 8.00 |
| New York, New Haven & Hartford: | | | | | | |
| Freight locomotive | .17 | .17 | 39 | 1640 | 1260 | 0.91 |
| Freight locomotive | .40 | .40 | 12 | 940 | 1260 | 1.34 |
| Passenger locomotive | .45 | .40 | 7 | 402 | 960 | 2.35 |
| Passenger locomotive | .50 | .45 | 6 | 352 | 960 | 2.67 |
| Passenger locomotive | .60 | .55 | 4 | 302 | 960 | 3.11 |
| Motor car | 1.30 | 1.20 | 5 | 324 | 1200 | 3.70 |
| New York Central: | | | | | | |
| Passenger locomotive | .20 | .20 | 18 | 700 | 2200 | 3.14 |
| Passenger locomotive | .40 | .40 | 13 | 550 | 2200 | 4.00 |
| Passenger locomotive | .60 | .55 | 9 | 378 | 2200 | 5.82 |
| Passenger locomotiv | .90 | .85 | 6 | 278 | 2200 | 7.90 |
| Passenger locomotive | 1.20 | 1.10 | 3 | 194 | 2200 | 11.34 |
| Motor cars | 1.30 | 1.25 | 8 | 493 | 2000 | 4.06 |
| Brooklyn Rapid Transit | 1.75 | 1.60 | 6 | 178 | 1600 | 9.00 |
| Manhattan Elevated | 1.33 | 1.30 | 6 | 154 | 1000 | 6.50 |
| Interboro Subway, 1908 | 1.30 | 1.10 | 8 | 361 | 2400 | 6.67 |
| Interboro Subway, 1911 | 1.40 | 1.20 | 10 | 360 | 3260 | 9.33 |
| Long Island-Pennsylvania | 1.40 | 1.40 | 6 | 321 | 2580 | 8.04 |
| Long Island-Brooklyn | 1.30 | 1.30 | 6 | 222 | 1600 | 7.21 |
| West Shore R. R | 1.00 | 1.00 | 2 | 80 | 600 | 7.50 |
| Erie R.R., motor car | ...... | ...... | 4 | 152 | 800 | 5.2 |
| Metropolitan Elevated, Chicago | 1.41 | 1.06 | 6 | 164 | ...... | |
| South Side Elevated, Chicago | 1.35 | 1.19 | 5 | ...... | 540 | |
| Northwestern Elevated, Chicago | .84 | ...... | 6 | ...... | 1280 | |
| Central London | 1.00 | 1.00 | 7 | 136 | 500 | 3.7 |
| Great Western | 1.55 | ...... | 6 | 194 | 640 | 3.3 |
| North-Eastern, England | .75 | .75 | 9 | 270 | 3000 | 11.1 |
| London, Brighton & S. C | 3.00 | ...... | 3 | 145 | 820 | 6.4 |
| | 3.00 | 2.50 | 4 | 190 | 1200 | 6.4 |
| Liverpool & Southport | 2.00 | 1.18 | 2 | 110 | 1200 | 10.9 |
| | 1.05 | .85 | 5 | 179 | 1200 | 6.7 |
| Midland Ry., England | 1.40 | 1.19 | 3 | 87 | 360 | 8.0 |
| (Dalziel & Sayer's data) | 1.30 | 1.14 | 3 | 83 | 300 | 7.3 |
| | 1.10 | 1.00 | 3 | 83 | 300 | 7.0 |
| Giovi Ry., Italy; 2.7% grade | .14 | .14 | 18 | 446 | 1980 | 4.4 |
| Great Northern, Cascade T.; 1.7% grade | .12 | .12 | 15 | 733 | 1700 | 2.3 |

The acceleration rate is governed by the h. p. capacity per ton, as well as by the speed-time service requirements. Tons of 2000 pounds.

ACCELERATION RATES OF ENGLISH RAILWAYS.

| Name of electric railway. | Specific acceleration m. p. h. p. s. | Distance between stops. ft. | Time of stop. | Schedule speed m. p. h. | Running speed m. p. h. |
|---|---|---|---|---|---|
| Liverpool Overhead....... | 1.79 | 2145 | 11 | 19.5 | 22.9 |
| Liverpool & Southport.... | 1.25 | 6535 | 15 | 30.0 | 33.4 |
| London Electric.......... | 1.06 | 2555 | 20 | 15.7 | 19.2 |
| Central London.......... | 0.90 | 2540 | 20 | 14.7 | 17.7 |
| North-Eastern........... | 0.71 | 6000 | 30 | 20.5 | 24.1 |
| Midland-Morcambe ....... | 0.35 | 23500 | 120 | 26.7 | 33.4 |
| London, Brighton & S. C . | 1.00 | 4300 | 20 | 22.0 | ...... |

DECELERATION RATES.

| | |
|---|---|
| Braking commonly used for electric trains........................ | 1.6 to 2.00 |
| Westinghouse magnetic brakes, Electric Railway Test Commission................................................ | 2.57 |
| Maximums, Electric Railway Test Commission..................... | 4.00 to 5.00 |
| Boston and Worcester interurban ................................ | 2.1 to 2.77 |
| Brooklyn Rapid Transit (Elevated Division)......................... | 1.50 |
| Manhattan Elevated R. R.......................................... | 1.75 to 1.85 |
| Ordinary steam railroad passenger train.......................... | 1.25 to 1.60 |
| Ordinary steam railroad freight train............................. | .70 to .80 |

## KINEMATICS OF ACCELERATION.

**Elementary kinematics** governing acceleration:

Pull, or pressure, or force $= F$, in pounds.

Mass $= M$ $=$ weight$/32.2$

Distance or space $= s$, in feet.

Time $= t$, in seconds.

Energy $= F \times s$, in foot-pounds. Power $= F \times s/550$, in h. p.

$F =$ rate of acceleration $\times$ mass.

$F = a \times$ weight in pounds$/32.2$ in feet per second per pound.

$F = a \times 5280/3600 \times W \times 2000/32.2$, in miles per hour per second per ton.

$F = a \times 91.1 \times$ No. of tons, in miles per hour per second per ton.

$F = a \times 100 \times$ tons, allowing 10 per cent. for energy of rotation.

This means that *in order to accelerate a train at the rate of* 1 *mile per hour per second, a force of* 100 *pounds per ton is required.*

Velocity in feet per second $v = s/t$

and $v =$ rate of acceleration $\times$ time.

Energy of rotation $= (1/2)M \times v^2 = F \times s$.

$F = (1/2)W/32.2 \times v^2/s$, in feet per second per second.
$F = 69V^2/s$, where V is in miles per hour per ton, and s is the distance in feet within which acceleration or deceleration takes place.
$F = 76V^2/s$, allowing about 10 per cent. (6 to 16) for energy of rotation.[1]

This means that *an accelerating or decelerating force must be* 76 *pounds per ton, times the square of the velocity in miles per hour, divided by the distance in feet.*

Distance in feet, s = velocity $\times$ time; and v = (ave.)a $\times$t.

Distance in feet is $s = (1/2)a \times t^2$, in feet per second and seconds.

*Example.*—A 1200-ton freight train is started by employing an accelerating force of 18,000 pounds, or 15 pounds per ton, in addition to the force required to overcome friction.

The rate of acceleration is then 0.15 m. p. h. p. s.; for to accelerate a train at the rate of 1 m. p. h. p. s. requires 100 pounds per ton.

The speed in m. p. h. is a $\times$t. The speed, at the end of a uniform acceleration period, for example 84 seconds, is $0.15 \times 84$ or 12.6 m. p. h.

One m.p.h.p.s. equals 1.466 feet per second. Distance run is $(1/2) \times a \times t^2 = (1/2) \times 0.15 \times 1.466 \times 84^2 = 775$ feet.

A 300-ton passenger train is started by using an acceleration force of 12,000 pounds, which is 40 pounds per ton; or the rate of acceleration used is 0.4 m.p.h.p.s. The speed in m. p. h. at the end of 60 seconds is $0.4 \times 60$, or 24 m. p. h.; and the distance run is $(1/2) \times 0.4 \times 1.466 \times 60^2$, or 1056 feet.

The same 300-ton passenger train in common rapid transit service would be accelerated at four times the above rate, or at 1.6 m. p. h. p. s. If maintained 30 seconds, the speed would be $1.6 \times 30$, or 48 m. p. h. The distance covered in 30 seconds is $(1/2) \times 1.60 \times 1.466 \times 30^2$, or 1056 ft.

## ENERGY FOR FREQUENT STOPS.

When the service requires frequent stops, the subject of energy and power becomes an important matter.

The kinetic energy in foot-pounds which is required to start or stop a train is $(1/2)Mv^2$, where M is the mass (pounds divided by 32.2) and v is the speed in feet per second.

*Example.*—A 55-ton car running at 60 m.p.h. The kinetic energy is $(1/2) \times 55 \times 2000/32.2 \times (1.466 \times 60)^2$, or 13,000,000 foot-pounds; or $13{,}000{,}000/(550 \times 60 \times 60) = 6.50$ h.p. for 1 hour. Assuming that the efficiency of the motor and of the control plan during the time when the train is accelerating from zero to full speed is 55 per cent., then the kw.-hr. to the motors are $746 \times 6.5/.55$, or 8.8, which might amount to 10 kw.-hr. at the electric power station. The train can attain full speed in about 1 minute and thus the average power expended for

[1] Storer: Inertia of Rotating Parts of a Train, A. I. E. E., Jan., 1902.

acceleration alone, during each start, is 10 kw.-hr. divided by 1/60 hour, or 600 kilowatts. The cost of energy at the rate of 2 cents per kw.-hr. is 20 cents, a relatively large sum to be paid per car per stop.

The example is a fair one and shows up the mechanical and the financial side of train service which requires frequent stops per mile. Frequent-stop, high-speed service is expensive.

The energy required for common interurban train service varies widely. For example, it was found that the average energy delivered from the central station to supply the motors on a 28-ton electric car which made long runs with very few stops between two cities was 2.30 kw.-hr. per car-mile, while the average energy with 10 stops per mile for service within the city limits was 4.75 kw.-hr. per car-mile.

Efficiency of motors during the accelerating period is low, from 50 to 70 per cent. These losses are not of relative importance when the number of stops does not exceed one per mile.

Operating expenses are increased by stops. For example the total operating cost as determined for a common railroad is 55 cents per average passenger train-mile, and the cost of each extra stop is 80 cents.

Frequent stop service thus increases the amount of energy, total cost of energy, running time, and cost of truck, car, and motor maintenance.

The energy required for the propulsion of rapid transit trains having a fixed schedule speed is least when the trains are started and stopped at the maximum rate of acceleration and deceleration. It is necessary, therefore, that trains which are to make numerous stops per mile be properly equipped. High rates of acceleration require that the motive power be placed at intervals thruout the train; it must not be concentrated on a few drivers, or on one or more locomotives.

Tables have been distributed by manufacturers of electric railway motors showing the average kilowatt input to trains of varying weight and composition, schedule speed, maximum speed, and stops per mile, with different motor gear ratios. These tables facilitate determinations of motor capacities. Such a table is given below.

AVERAGE KILOWATT INPUT WITH VARYING STOPS PER MILE.
Single-car Operation.

| Stops per mile. | 1/8 | 1/4 | 1/2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| 20-ton car | | | 51 | 36 | 29 | 26 | 24 | 23 | 22 | 22 |
| 30-ton car | | 96 | 69 | 51 | 40 | 36 | 33 | 32 | 31 | 31 |
| 40-ton car | 176 | 119 | 85 | 63 | 51 | 45 | 43 | 41 | 40 | 40 |
| 50-ton car | 195 | 130 | 94 | 73 | 61 | 55 | 52 | 50 | 49 | 49 |
| 60-ton car | 200 | 140 | 106 | 82 | 70 | 64 | 62 | 60 | 59 | 58 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Two-car Trains.** | | | | | | | | | | |
| 2–20-ton cars | | | 78 | 60 | 50 | 45 | 43 | 41 | 40 | 40 |
| 2–30-ton | | 137 | 104 | 80 | 69 | 64 | 62 | 60 | 59 | 58 |
| 2–40-ton | 228 | 160 | 124 | 103 | 89 | 82 | 79 | 77 | 76 | 75 |
| 2–50-ton | 255 | 183 | 147 | 125 | 111 | 103 | 99 | 97 | 95 | 94 |
| 2–60-ton | 282 | 202 | 165 | 144 | 127 | 117 | 115 | 113 | 111 | 110 |
| **Three-car Trains.** | | | | | | | | | | |
| 3–20-ton cars | | | 102 | 76 | 67 | 63 | 61 | 60 | 59 | 58 |
| 3–30-ton | | 173 | 135 | 112 | 97 | 90 | 88 | 86 | 84 | 83 |
| 3–40-ton | 280 | 200 | 164 | 140 | 127 | 117 | 115 | 113 | 111 | 110 |
| 3–50-ton | 300 | 236 | 198 | 172 | 155 | 145 | 142 | 139 | 137 | 136 |
| 3–60-ton | 342 | 263 | 219 | 191 | 175 | 167 | 163 | 160 | 158 | 157 |
| **Five-car Trains.** | | | | | | | | | | |
| 5–20-ton cars | | | 144 | 124 | 110 | 102 | 98 | 97 | 95 | 94 |
| 5–30-ton | | 238 | 196 | 171 | 154 | 145 | 142 | 139 | 137 | 136 |
| 5–40-ton | 370 | 292 | 246 | 216 | 197 | 188 | 183 | 180 | 178 | 176 |
| 5–50-ton | 438 | 350 | 302 | 270 | 250 | 236 | 228 | 225 | 222 | 220 |
| 5–60-ton | 497 | 400 | 352 | 314 | 290 | 280 | 275 | 271 | 266 | 263 |

## POWER FOR AUXILIARIES.

Lighting and ventilation of cars generally require 1 kilowatt per passenger car. Swiss Federal Railway allows 2 candle power per seat. Shops and passenger stations require 1 kilowatt per 100 square feet.

Brakes are seldom electrically operated.

Signals require about 1 per cent. of the total power used for trains.

Heating by electricity is decidedly expensive compared with heating by coal. Electric heat is used for rapid transit service to obtain cleanliness, space, and minimum care; or when the cost of electric power is low. Electric heating during 3 months of the year in the northern states requires about 400 watts per ton, or 12 kilowatts for a 30-ton car. West Jersey & Seashore Railroad uses 63 watt-hours per ton-mile, measured at substations, for summer service, and 100 for winter service, the difference being used largely for heating the cars in winter. Swiss Federal Railway allows 156 watts as a maximum per seat.

## LOSSES AT MOTORS.

To the mechanical power required, the losses at motors, the friction, magnetic, commutator, contact, control and heating losses, are added. Motor and gear friction on motor cars is equivalent to about 50 pounds tractive effort per motor.

**LOSSES BEYOND MOTORS.**

These are the losses in transmission and contact lines, transformers, and substations where used.

Efficiency of transmission, from the power station output to the rotary converter substation output, is 70 to 85 per cent., varying inversely with the output. Third-rail and track-return losses reduce the

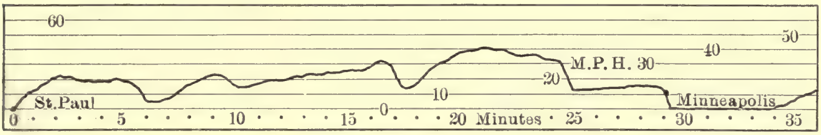


FIG. 169.—TYPICAL CURVE ON RELATION OF SPEED TO TIME.
Great Northern Railway eight-car passenger train number 1, The Oriental Limited. Curve by Schalter speed recorder.

above efficiency 5 to 20 per cent., depending upon the distance and loads, making the total efficiency 50 to 65 per cent. When high-voltage contact lines are used, and substations are omitted, the efficiency varies from 65 to 85 per cent.

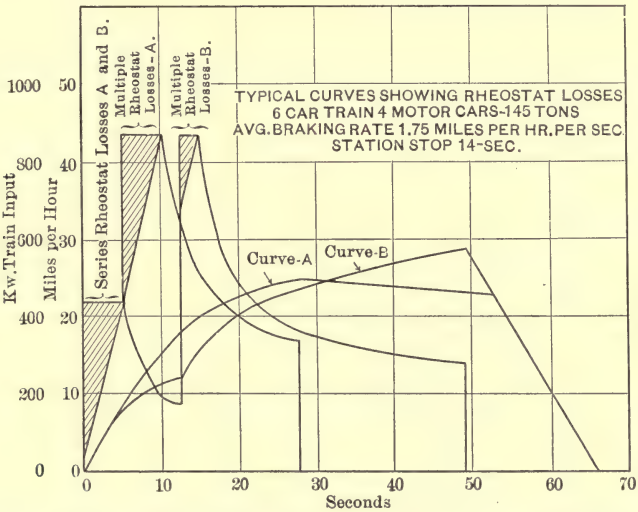


FIG. 170.—POWER, SPEED, AND TIME CURVES OBTAINED BY PUTNAM ON THE MANHATTAN ELEVATED RAILWAY.

**POWER CURVES.**

To illustrate the change of speed or tractive effort with reference to time or to distance, power curves are used. See Fig. 169. Illustrative curves, in simplest form, from Putnam's paper on "Power Economy on Manhattan Elevated Railroad," to A. I. E. E., July, 1910, are also shown.

### WATT-HOURS PER TON-MILE.

The energy which is required for trains is generally expressed in watt-hours per ton-mile. The energy required is proportional to, and dependent on, the tractive effort required per ton to overcome friction, inertia, and grades. The energy required per ton-mile does not depend on the speed. It is not a function of the speed but of the resistance. High speed, however, increases the friction or tractive effort.

The average numerical value of the tractive resistance, or the values of the train resistance for different speeds and combinations of cars in the train, were given in the tables on tractive resistance. The tables are for trains on a level tangent at uniform motion. The added resistance for the grades, track curves, and rate of acceleration, is readily

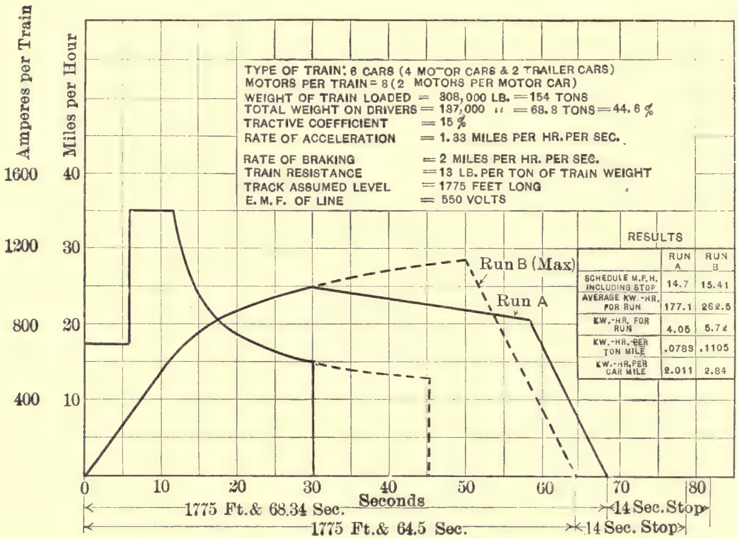


FIG. 171.—POWER, SPEED AND TIME CURVES.
Manhatten Elevated Railway. Putnam.

computed from the data given. The energy required to accelerate the train from rest to full speed can be obtained by computing the value of 1/2 $Mv^2$ in foot-pounds and in kilowatt-hourrs, as illustrated.

The average tractive effort required to overcome inertia, or to accelerate the train, is most easily determined by diagrams made to show the tractive force required during the acceleration period. This is governed partly by the motor characteristics, and also by changes in motors by series-paralleling, concatenation, pole change, voltage variation, field variation, etc. The average tractive force during a given period or cycle, including the time for the train stop, can be determined mathematically or by diagrams. HOBART: "Heavy Electrical Engineering," Chapter X.

### WATT-HOURS PER TON-MILE.

*Rule.—The watt-hours per ton-mile are found by multiplying the tractive resistance, in pounds per ton, by* 2. (approx.) Proof:

H.p. $=$ tractive effort in total pounds, R, $\times$ speed in m.p.h. /375.

H.p.-hours per ton-mile $=$ R $\times$ m.p.h. $\times$ hours /(375 $\times$ tons $\times$ miles).

Watt-hours per ton-mile $=$ R $\times$ m.p.h. $\times$ hours $\times$ 746 /(375 $\times$ tons $\times$ miles).

$=$ R $\times$ 746 /(375 $\times$ tons) $=$ R per ton $\times 2$.

The rule is useful for rapid work and quick conceptions of problems. It applies to grades, curves, and acceleration, and for level tangents. Power losses in motors, controllers, and transmission line, are not included.

*Example in power and energy.*—Assume the average tractive resistance due to friction, grades, etc., as 15 lb. per ton; a 600-ton train; a 108-mile, 4-hour trip at 27 m.p.h.; motor and control efficiency of 80 per cent.

| | |
|---|---|
| Mechanical h. p. output averages $600 \times 15 \times 27/375$, or | 648 |
| Watt-hours per ton-mile average $2 \times 15$, or | 30 |
| Kilowatt hours of work total $.030 \times 600 \times 108$, or | 1944 |
| Energy: Kilowatt hours to the motors, total 1944/.80, or | 2430 |
| Power: Kilowatts to the motors, average 2430/4, or | 607.5 |

The motors must be designed with such continuous capacity that the root-mean-square of the electric power input will not exceed 607.5 kv.-a.

*Example.*—Ascent of the Cascade Mountains by G. N. Ry. eastbound trains is on a 2.2 per cent. grade for 25 miles. The tractive effort per ton for the grade is 44 pounds, the friction at usual speed is 6 pounds, and the total is thus 50 pounds per ton. The work or energy required at the wheel rim is then 100 watt-hours per ton per mile, quite independent of the speed. The 25-mile run with a 1600-ton train requires $.100 \times 1600 \times 25$, or 4000 kw. hr. If the average speed is 12.5 m.p.h. for a 2-hour run, then the average power required at the drivers is 2000 kilowatts. The efficiency of motor, transformers, and lines is about 69 per cent. The power from the water power plant is 2900 kilowatts or 4000 mechanical horse-power.

Three 1700-h. p. electric locomotives are now used to haul each 2000-ton freight train up the 1.7 per cent. tunnel grades.

**Watt-hours per ton-mile** required for moving trains equal twice the tractive resistance in pounds per ton. An average tractive resistance for many trains approximates 10.5. This is about the resistance per ton for 10- to 40-car freight trains at 30 to 40 m.p.h.

Three-car passenger trains, 135 tons, at 30 m.p.h.

Four-car passenger trains, 140 tons, at 30 m.p.h.

Eight-car passenger trains, 360 tons, at 35 m.p.h.

The watt-hours per ton-mile at 70 per cent. efficiency for motors and line are thus $(10.5 \times 2)/.70$ or 30.

Grades compensate themselves, and do not materially increase the energy required, so long as the brakes are not applied too much of the time. The power required varies with the grade.

Acceleration of trains increases the average watt-hours per ton-mile, since the energy required in starting is higher than in running, even with the offset due to the absence of energy while coasting, braking, and stopping. For example, the average energy is estimated in the following table.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Length of the train run in miles......... | 20 | 15 | 10 | 5 | 4 | 3 | 2 | 1 |
| Watt-hours per ton-mile at station....... | 30 | 31 | 33 | 38 | 40 | 45 | 52 | 70 |

The data are good for the wide range of speed noted above.

## REGENERATION OF ENERGY.

Regeneration of energy may be effected by mechanical and by electric methods, as will now be explained briefly.

**Compensation** for inertia and frictional resistance is often effected mechanically, particularly in rapid transit service, by elevating the track at stations where local stops are made regularly, in order to store and to utilize potential energy. Compensation is not so practical where the express trains do not stop at the majority of the stations, because smooth riding may be prevented, if the elevation of the track is appreciable.

Central London Railway uses 1.66 per cent. up-grade approach to stations to retard the train and to store energy, and uses a 3.30 per cent. down-grade, half as long, to assist in accelerating the train in leaving the station. The pull due to the down-grade is 66 pounds per ton, which, deducting friction, allows a high ratio of acceleration with a small amount of electrical energy.

Manhattan Elevated Railroad takes advantage of such compensation at a few stations, where changes of grade are necessary for other reasons.

In rapid transit service about 40 per cent. of the entire energy is consumed in braking, and theoretically this can be saved by regeneration.

Regeneration by electric motors saves energy which would otherwise be lost in the friction of brake shoes on wheel tires. Regeneration involves the generation of electrical energy by the driving motors, the return of this energy to the line, and to other locomotives, or to the power station. The amount saved depends upon the steepness and length of the grades, and may vary from 20 to 50 per cent. of the total energy to the motor. The efficiency of regeneration varies from 60 to 75 per cent. and increases with the number of trains.

Trains running down grade regenerate energy to haul trains up the

grade on the other side of the summit of the mountain, thus saving in line loss when concentrated loads are hauled. With a double track, a train can advantageously start down the grade when another train starts up the grade; or with regeneration on a single-track road, trains can meet advantageously in the middle of a long grade.

The energy available in stopping a train varies as the square of the speed at the time when brakes or regeneration is applied. The energy is $(1/2)\ MV^2$ in foot-pounds. For example, a 1000-ton train at 30 m. p. h. or a 250-ton train at 60 m. p. h., have equal amounts of stored energy. The foot-pounds in the later case are $(1/2) \times 250 \times 2000 \times 88 \times 88/32.2$, or 60,000,000. If such a train is stopped in 60 seconds, the power to be gained in regeneration, or destroyed in braking, averages 1820 h. p.

The down-grade must exceed 0.4 per cent., assuming train friction of 8 pounds per ton, before energy can be generated by the motors. With 1.4 per cent. grade the power generated and delivered to the line at 70 per cent. motor efficiency, by a 1200-ton train at 15 m. p. h., would be $20\ (1.4-.4) \times 1000 \times 15 \times .70/375$, or 560 h. p.

Where stops are infrequent, the effect of regeneration on economy is negligible. In any case the torque of the motor approximates zero in stopping, and air brakes must be used in connection with regeneration.

**Regeneration with direct-current motors** requires shunt-wound motors. These were successfully tried in 1887 on the New York Elevated Railway.

The motor field was weakened to increase the speed, and, in slowing down, strengthened to send current back to the line and later to a local rheostat circuit. No brakes were used. But the series motors have too many physical advantages, among them tremendous overload capacity, speed, and commutating characteristics and the shunt motors used were abandoned. Sprague: A. I. E. E., May, 1899, page 239; May, 1907, page 713; E. E., Oct. 18, 1893, page 339.

Sprague showed that a reduction of 40 per cent. could be effected in the capacity of a central station.

Shunt motors were abandoned because:

1. Motors require fine wire field windings which are not hardy. The horse power so developed is relatively low.
2. Equalization of motor characteristics is necessary.
3. Driver diameters must be alike, or some motor will be overloaded.
4. Speed-torque characteristics are not the most desirable for rapid transit work. They cannot be applied to variable speed railroad service.

**Regeneration with three-phase motors** was first commercially developed about 1902 by Ganz Electric Company for the infrequent service on grades of the Valtellina Railway in Italy. The regenerative feature, as

applied, reduces the fluctuations of the load at the power house to 1.8 times the average load. In case of a heavy load on the power house, the speed of the water wheels and all trains is reduced, and some trains fed back into the line. The trains constituted the equivalent of a gigantic flywheel and reduced the power-house fluctuations in load and speed. The load fluctuations are particularly large with three-phase motors.

Stillwell refers to a test on a 7-car train, to the lack of complication in running down grades, and to the fact that more than 70 per cent. of the energy regenerated was restored to the line, and this figure would have been higher with steeper grades. In a specific case Ganz guaranteed to regenerate over 20 per cent. of the total energy. Cserhati: St. Ry. Journ., Aug. 26, 1905, p. 303.

Armstrong notes that, in the case of the Great Northern Railway, two trains running down a grade could, with recuperative power, haul one train up the grade on the other side of the mountain.

**Regeneration with single-phase motors** is effected by varying the taps on the transformers from which the locomotive motors obtain excitation. The ratio of transformation, the e. m. f., and the rate of electric power so generated by the motors on the down-grade are thus varied. Motor designs have compensating windings to neutralize the armature reaction, and this permits of a wider range of armature current and field excitation than is permissible with ordinary series direct-current railway motors. Wm. Cooper: A. I. E. E., June, 1907, p. 1469; St. R. J., p. 1145, June 19, 1907. Single-phase regeneration on grades is carried out to commercial advantage on European roads; particularly, the French Southern (Midi) Railway on its long hilly divisions.

**Regeneration in practice** is applied for safety of operation. Electric braking or regeneration is used normally, and the air brakes are held in reserve. Economy of train operation requires coasting after the motors have attained full speed. On the light down-grades, the train will often run at high speed. Ordinarily, regeneration will not be desirable.

a. Regeneration of energy has no great advantages, nor can the saving in energy be large, on ordinary railroads. It has advantages for service on long, steep, mountain grades.

b. Increased safety on grades makes it a valuable adjunct.

c. Simplicity and reliability are not sacrificed.

d. Motor capacity must be increased for frequent stop or rapid transit service and the capacity, weight, and cost may even be doubled. The capacity of motors, cooled with forced draft, in trunk-line mountain-grade freight service, need not be increased.

e. Regeneration tends to smooth out the load, to increase the load factor, and economy of power production; and, since the load factor is low in the three-phase system, regeneration is of economic importance.

f. Cost of the generating plant, transformers, and transmission lines for long trunk-line mountain-freight service, is decreased.

Good data are not yet available.

### SUMMARIES ON POWER REQUIRED.

**General Consideration.**—The motive power equipment of steam railroads of the United States on June 30, 1910, was about 60,000 steam locomotives. This number divided by the aggregate length of the steam railroad route length, 240,000, gives .25 locomotives per mile of road; or divided by the sum of the single, second, third, fourth tracks, yards, and sidings, namely 350,000 miles, gives .17 locomotives per mile of single track operated. The average number of square feet of heating surface is 2053. Using the constant 0.43, the average horse power is about 884. There were 220 h.p. per mile of road, or 150 h.p. per mile of single track.

Pennsylvania Railroad has about 550 h.p. per mile of route, and Pittsburg & Lake Erie, and the Bessemer & Lake Erie, which have heavy freight service, require about 1000 h.p. per mile of route.

The amount of equipment used by electric railroads per mile of track is noted in the table which follows.

POWER EQUIPMENT USED PER MILE IN SINGLE TRACK.

| Name of railway. | Locomotives. | | | Motor cars. | | | Total. h.p. | Mileage. | Total h.p. per mile. |
|---|---|---|---|---|---|---|---|---|---|
| | No. | h.p. | Total h.p. | No. | h.p. | Total h.p. | | | |
| New Haven | 41 | 960 | ........... | 2 | 500 | | | | |
| | 2 | 1260 | 42,480 | 2 | 250 | 3,900 | 46,380 | 100 | 464 |
| | 1 | 600 | ........... | 4 | 600 | | | | |
| Boston & Maine | 5 | 1340 | 54,000 | 0 | 0 | 0 | 54,000 | 22 | 245 |
| Pennsylvania-LongIsland | 33 | 2500 | 82,500 | 225 | 430 | 96,750 | 179,250 | 95 | 1887 |
| Long Island | 0 | 0 | 0 | 136 | 400 | 54,400 | 54,400 | 164 | 332 |
| West Jersey and Seashore | 0 | 0 | 0 | 108 | 480 | 51,840 | 51,840 | 154 | 336 |
| Interboro. Subway | 0 | 0 | 0 | 910 | 480 | 43,680 | 43,680 | 85 | 5139 |
| Hudson & Manhattan | 0 | 0 | 0 | 200 | 320 | 64,000 | 64,000 | 18 | 3555 |
| Baltimore & Ohio | 12 | ..... | 11,600 | 0 | 0 | 0 | 11,600 | 7 | 1657 |
| Baltimore & Annapolis | 0 | 0 | 0 | 12 | 400 | 4,800 | 4,800 | 35 | 1371 |
| New York Central | 47 | 2200 | 103,400 | 125 | 480 | 60,000 | 163,400 | 150 | 1089 |
| West Shore | 0 | 0 | 0 | 21 | 300 | 6,300 | 6,300 | 114 | 55 |
| Erie Railroad | 0 | 0 | 0 | 6 | 400 | 2,400 | 2,400 | 40 | 60 |
| Grand Trunk | 6 | 720 | 4,320 | 0 | 0 | 0 | 4,320 | 12 | 360 |
| Michigan Central | 6 | 1100 | 6,600 | 0 | 0 | 0 | 6,600 | 19 | 347 |
| Twin City Rapid Transit. | 2 | 200 | 400 | 600 | 200 | | | | |
| | | | | 100 | 240 | 174,000 | 174,400 | 380 | 459 |
| | | | | 100 | 300 | | | | |
| Rotterdam-Hague-Scheveningen. | .... | 0 | 0 | 19 | 360 | 6,840 | 6,840 | 48 | 143 |
| Giovi Ry | 20 | 1980 | 39,600 | .... | 0 | 0 | 39,600 | 26 | 1525 |

*Note.*—The average steam railroad traffic in the United States passing a given point in each direction does not exceed 7 trains per day.

EQUIPMENT AND ENERGY USED BY BROOKLYN RAPID TRANSIT CARS.

| No. of motor cars. | Ave. wt. of cars loaded. | Motors no. per car and name. | H. p. of each motor. | Gear ratio used. | Max. speed m. p. h. | Watt-hours per ton-mile. |
|---|---|---|---|---|---|---|
| 327 | 29 | 4–101B W | 40 | 5.00 | 23.50 | 157 |
| 112 | 19 | 2–93A2 W | 60 | 4.12 | 28.75 | 178 |
| 754 | 19 | 2–81 W | 60 | 4.38 | 28.25 | 172 |
| 143 | .......... | 2–68 W | 40 | 4.86 | 22.00 | ........ |
| 92 | 19 | 2–64 GE | 60 | 4.12 | 21.50 | 140 |
| 125 | 29 | 4–80 GE | 40 | 4.36 | 29.00 | 164 |
| 659 | 39 | 2–300 W | 200 | 3.37 | ........ | .......... |

Stop per mile not given. E. R. J., June 12, 1909, p. 1073.

EQUIPMENT AND ENERGY USED FOR MOTOR–CAR TRAINS.

| Name of railway. | Cars per train. | Weight in tons. | Schedule speed m. p. h. | Stops per mile. | H. p. of motors. | H. p. per ton. | Watt-hr. at car per car-mile. |
|---|---|---|---|---|---|---|---|
| London Electric: | | | | | | | |
| Metropolitan....... | 4 | 141 | 15.7 | 2.1 | 800 | 6.2 | 2,220 |
| Bakerloo.......... | 3 | 71 | 15.04 | 2.35 | 400 | 5.6 | 2,270 |
| Great Northern .... | 4 | 88 | 16.22 | 2.35 | 400 | 4.5 | 1,970 |
| Charring Cross..... | 4 | 85 | 16.05 | 2.57 | 400 | 4.6 | 2,320 |
| Central London...... | 7 | 132 | 14.0 | 2.1 | 500 | 3.8 | .......... |
| North-Eastern ....... | .... | 101 | 22.0 | 0.9 | ....... | 5.0 | .......... |
| Boston Elevated...... | 6 | 200 | .......... | ...... | 2100 | 10.5 | .......... |
| Manhattan Elevated.. | 6 | 148 | 14.7 | 3.0 | 1000 | 7.0 | 2,750 |
| | 5 | 224 | .......... | ...... | 1440 | 6.5 | .......... |
| Interboro Subway.... | 10 | 361 | 16.2 | 2.6 | 2400 | 6.7 | 2,890 |
| | 10 | 360 | 23.0 | ...... | 3360 | 9.3 | .......... |
| Armstrong's data: | | | | | | | |
| A. I. E. E., Jan. 1904 | ...... | 100 | 19.0 | 2.0 | 630 | 6.3 | .......... |
| p. 70. | | | 27.0 | 1.0 | 1000 | 10.0 | .......... |
| | | | 40.0 | 0.5 | 1800 | 18.0 | .......... |
| Valtellina Ry........ | 6 | 165 | .......... | ...... | 600 | 3.6 | .......... |
| Berlin Zossen: | | | | | | | |
| A. E. G. 3-phase. | 1 | 101 | 100.0 | ...... | 1000 | 10.0 | .......... |

## ENERGY REQUIRED FOR MOTOR-CAR TRAINS PER TON-MILE AND PER CAR-MILE.

| Name of railway. | Miles per stop. | Sch. speed m.p.h. | Cars per train. | Train or service characteristics. | Watt-hours per ton-mile. a.c. | Watt-hours per ton-mile. d.c. | Watt-hours per car-mile. a.c. | Watt-hours per car-mile. d.c. |
|---|---|---|---|---|---|---|---|---|
| Boston Elevated | | | 6 | Elevated | | | | |
| Manhattan Elevated | 0.33 | 14–15 | 5–8 | Elevated | 82 | 70 | | 2750 |
| Brooklyn Elevated | | | 3–6 | Elevated | 170 | | | |
| Interboro Subway | | 13 | 5 | Local service | | 79 | | 2890 |
| Interboro Subway | | 23 | 10 | Real rapid transit | | 58 | | 2260 |
| New York Central | 1.25 | 24–30 | 6–8 | Terminal & suburban | | | | |
| Long Island R.R. | 1.60 | 25 | 4 | Brooklyn suburban. | 111 | 90 | 4040 | 3280 |
| West Jersey & Seashore | | | 6 | Heavy summer traffic. | 84 | | | |
| | | | 4 | Light winter traffic, with electric heat. | 139 | | | |
| Lake Shore Electric | | | 1 | City service | 91 | | | |
| | | | 1 | Interurban service | 126 | | | |
| Marion, Bluffton & E. | | | 1 | E.R.J., May 1, 1909 | | 85 | 2710 | |
| Chicago, Lake Shore & South Bend. | | | 1–3 | Heavy motor-car trains. | 98 | | | |
| Twin City Rapid Transit | | 10.0 | 1 | City and interurban | 200 | | 4750 | |
| London Electric | 0.44 | 15.7 | 4 | Suburban traffic | | | | 2820 |
| Central London | 0.47 | 14.7 | 7 | Suburban traffic | 50 | | | |
| City & South London | | | 4 | Suburban traffic | 55 | | | |
| Lancashire & Yorkshire | | | 4 | Ordinary railroad | 80 | | | |
| London, Brighton & S.C. | | | 3 | London suburban | | | | |
| Blankanese-Ohlsdorf | | | 2 | Heavy suburban | | | | |
| Valtellina Ry.: | | | | | | | | |
| Locomotive | | | 3–6 | Light ry. service | 86 | | | |
| Motor car | | | | | 62 | | | |
| Average | | | | | 71 | | | |

Measurements were made at the a.c. generator bus-bar at the power plant, and at the d.-c. third-rail or trolley feeders at the substation.

## ENERGY REQUIRED FOR NEW YORK, NEW HAVEN AND HARTFORD ELECTRIC LOCOMOTIVE HAULED TRAINS.

| Location of division. | Length miles. | Service noted. | Train tons. | Speed m.p.h. | No. of stops. | Ave. kw. | Watt-hours per ton-mile. | R, per ton. |
|---|---|---|---|---|---|---|---|---|
| Stamford to Woodlawn, N. Y. | 20.52 | Express passenger. | 488 | 49.0 | 0 | 1010 | 30.0 | 12.0 |
| Woodlawn to Stamford, Conn. | 20.52 | Express passenger. | 477 | 44.7 | 0 | 860 | 35.0 | 14.0 |
| Stamford to Woodlawn, N. Y. | 20.52 | Local passenger. | 316 | 22.1 | 13 | 790 | 85.4 | 34.1 |
| Woodlawn to Stamford, Conn. | 20.52 | Local passenger. | 285 | 22.1 | 13 | 740 | 74.2 | 29.7 |
| New Rochelle, N. Y. to Stamford, Conn. | 16.90 | Local passenger. | 500 | 26.4 | 9 | 777 | 58.8 | 23.5 |
| New Rochelle, N. Y. to Stamford, Conn. | 16.77 | Thru freight. | 1428 | 36.8 | 0 | 1370 | 25.9 | 10.4 |

See foot notes for above table on next page.

Passenger locomotive weight was 102 tons.

Freight locomotive, geared, 071, weight was 140 tons.

Efficiency of the locomotive motors and auxiliaries approximated 80 per cent. Watt-hours per ton-mile divided by 2.0/.80 gives the average tractive resistance per ton for acceleration, grades, curves, and train friction. See also page 414.

**Reference:** Murray to A. I. E. E., April, 1911. Tests, February, 1911.

Watt-hours per ton-mile are a function of the number of stops, speed, and air resistance, and number of cars per train.

Power required if all steam railroads used electric power is roughly 7 kilowatts per mile of single track.

Swiss Federal Railway Commission, which has reported on the amount of energy required to move all of the steam trains in Switzerland, agreed on the following basis for tractive resistance: In express service, from 12 to 21 pounds per 2000 tons; in passenger service, from 11 to 12.4 pounds; Gotthart line, with less favorable conditions, 14.8 pounds; for narrow-gage lines, 24.6 pounds. To the theoretical energy required for starting at stations and for running, 30 per cent. was added for passenger and freight trains, and 110 per cent. for express trains, to allow for changes in speed during running, and for starting after signal stops and slow down.

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## CHAPTER XII.

# TRANSMISSION AND CONTACT LINES.

**Outline.**

**Status of Development.**

**Energy Losses:**

Energy losses with low voltages, alternating current for important transmissions, energy losses with converter substations, transmission of three-phase current to motors, transmission of single-phase current to motors, design of apparatus for high voltages, development of high voltages for railways, voltages required.

**Laws Governing Transmissions.**

**Impedance and Resistance.**

**Transmission Line Engineering:**

Financial basis, electrical energy, location, voltage and cycle, materials available, specifications for materials, results to be anticipated.

**Insulators.**

**Data on High-voltage Transmissions.**

**Data on Steel Towers for Transmission Lines.**

**Contact Lines:**

Voltages used, design of contact lines, collection of current, by trolley, shoes, pantograph, and bows; two-trolleys wires for three-phase motors.

**Catenary Construction.**

**Third-rail Contact Lines.**

**Cost of Constructions:**

Insulators, poles, towers, bridges, catenary, third rail.

**Literature.**

## CHAPTER XII.

## TRANSMISSION AND CONTACT LINES.

### STATUS OF DEVELOPMENT.

A study of the development of electric power transmission shows that the first electric railways used direct current and a potential of 100 to 250 volts, and that the two conductors were the two track rails. An independent, insulated, positive third rail was soon added, but an overhead trolley contact line was usually substituted for the exposed third rail. Practical street railways in 1888 used 450 volts; but since 1896, the voltage has generally been 600. Direct current, with 660 volts on the contact line, is now used by most of the interurban railways and by electric divisions of terminal railroads. Where heavy trains are operated, economy of investment and of energy demand potentials of 3000 to 12,000 volts, the actual voltage depending upon the speed, number, and weights of individual trains, and the distances involved.

Electrification in the larger sense is chiefly a matter of power transmission; and in the development of the art, energy for electric trains has been generated and transmitted as alternating current. Three steps in the development of transmissions are noted.

a. A single-phase power transmission plant was installed in 1890 at Telluride, Colorado, from which a Westinghouse single-phase alternator of 100 h. p., the largest then made, transmitted energy at 3000 volts over a distance of 2.6 miles to a similar motor at the end of a transmission line.

b. Three-phase power transmissions were introduced in 1891 by Ferraris, at the Frankfort Exposition, when 100 h. p. was transmitted as three-phase current at 20,000 volts, a distance of 112 miles. E. E., Sept., 1891.

c. Three-phase long-distance power transmission for commercial service began with 11,000 volts about the year 1895 in California, and in 1896 between Niagara and Buffalo. This at once allowed an extension of electric roads, since several thousand horse power could be transmitted economically over distances of twenty to thirty miles. The line voltage could be reduced at substations along the route by step-down transformers, and the alternating current could be converted from three-phase to direct current for standard railway motors. This plan was soon adopted by the leading electric railway. See details, under "Electric Systems," Chapter IV.

### ENERGY LOSSES.

**Losses with low voltages** are large when, with a reasonable expenditure for copper lines, electrical energy is transmitted at low potentials, over distances of several miles for the propulsion of electric trains. For example, when 1200 kilowatts are transmitted at 1200 volts pressure, over a distance of only 12 miles, by twelve 1,200,000 c.m. copper feeders to deliver 1200 h. p. to haul *one* common passenger or freight train, the

transmission loss in the feeder and return circuit is 5 per cent. per train. If 12 trains are to be operated in the division, it becomes necessary to place expensive rotary converter substations about 12 miles apart, and to add heavy out-going and return cables. The losses are quadrupled when 600 volts are used, but are one one-hundredth as large when 12,000 volts are used.

**Alternating current** at high voltage is required in order to reduce the losses in long important power transmissions. Electricity then furnished a very efficient, simple, and convenient means for the transmission of large powers over long distances to heavy individual train units. This is an inherent advantage of electricity over steam, for common long-distance railroad work.

**Energy losses with converter substations are large** because of the low efficiency of normally underloaded rotary converters, storage batteries, and auxiliaries. The transformation and conversion of the energy to direct current at many small substations involves a relatively heavy investment. High efficiency, economy of labor and of investment require the equipment to have a high load factor and uniform traffic. Such conditions are seldom found in converter substations.

Examples from the practice of two large electric railroads are given to show the amount of the converter substation losses.

TRANSMISSION LOSSES ON WEST JERSEY & SEASHORE RAILROAD.

75 miles of route; 8 rotary converter, 675-volt, d.c. substations.

| | |
|---|---|
| Alternating-current, kw-hr. to transmission lines, August, 1906 | 2,244,020 |
| Direct-current, kw-hr., from converter substations | 1,694,770 |
| Kw-hr. lost in transmission line, transformers, and converters | 549,250 |
| Per cent. of energy lost | 24.4 |
| Alternating-current kw-hr. to transmission lines, March, 1909, | 1,850,000 |
| Kw-hr. lost in transmission, transformers, and converters | 519,310 |
| Per cent. of energy lost | 28 |

Average loss in 1907 was 27.8 per cent.; 1908, 26.2; 1909, 21.6; 1910, 20.4 per cent.

Loss in the 675-volt third-rail is estimated at 15 per cent., making the total loss between station and cars over 40 per cent. A change to 1200 volts would save part of the loss in the third rail and track.

TRANSMISSION LOSSES ON NEW YORK CENTRAL RAILROAD.

| | |
|---|---|
| Cost of power delivered from power station | 0.58 ¢. per kw-hr. |
| Cost of power delivered from substations | 0.77 ¢. per kw-hr. |
| Cost of power delivered to locomotive | 1.09 ¢. per kw-hr. |

This indicates a loss between locomotive and power house of nearly 50 per cent. The 660-volt, direct-current, third-rail system is used, and the 45 miles of route require nine rotary converter substations.

These railroads were electrified in 1906, prior to the development of high-voltage, alternating-current contact lines.

For additional data on transmission and converter losses see tables on (relative) "Cost of Steam-Electric Power per Kilowatt Hour," also "Watt-hours per Car-mile, at power plant and from substations."

Interurban railways in Indiana and Ohio with rotary converter substations deliver less than 50 per cent. of the electric power generated to the motors on the heavy single cars. Analysis of losses show step-up and -down transformer losses 13 per cent., transmission 3 per cent., rotary converters 20 per cent., direct-current distribution 21 per cent.

**Transmission of three-phase current** at 3000 volts and 15 cycles, and the application of electric power to locomotives, without the use of rotary converter substations, have been used by several roads in Italy, since 1902. The voltage used, 3000, is applied directly on the motor field windings. The use of 3000-volt contact lines for heavy train haulage requires frequent step-down transformer substations, because the drawbar pull from the motors decreases inversely as the *square* of the motor voltage, and the latter must therefore be well maintained.

Nine substations are required for 66 miles of the Valtellina Railway with light traffic; 4 substations for 12.5 miles of the Giovi Railway with heavy traffic; 2 stations for the Simplon Tunnel, a 12-mile, single-track road; 14 substations on the Burgdorf-Thun, 26-mile, 750-volt interurban road.

**Transmission of single-phase, high-voltage current** and its utilization by railway motors, without transformation and conversion to direct current, is a development which began in 1904. Westinghouse engineers, among them Mr. B. G. Lamme, after many engineering struggles, equipped the first single-phase road, the Indianapolis and Cincinnati Traction, 46 miles of track, with a 3000-volt contact line. The next long single-phase roads, Spokane and Inland Empire, and others, used 6600 volts. The use of 11,000 volts on the trolley, directly from the generator, *without line transformers and converter substations*, by the New York, New Haven & Hartford, and many other roads, since 1907, for long-distance haulage of heavy individual train units, marked an epoch in the transmission of energy for railroad transportation.

**Design of suitable apparatus** necessarily preceded the transmission and utilization of electrical energy at the high voltage required for heavy, high-speed electric trains.

a. Alternators were changed from a type in which the revolving element carried the high-voltage coils to a type in which the stationary element carried the high-voltage coils. This increased the space available and arranged for improved coil insulation. Voltages above 3500 became common after 1897, and voltages of 12,000 are now common.

b. Transformers were improved, about 1896, by a change in design from the air-blast type to the oil-insulated, water-cooled type. In large transformers these improvements, with extra insulation on the end coils, and greater rigidity allowed potentials of 20,000, 40,000, 60,000, and higher voltages for reliable work.

c. Lightning arresters were designed which protected apparatus and lines against break-down from static discharges. Improvements were made in the spark-gap, horn, and electrolytic cell types; also in methods of installation. Ground wires were strung over the transmission.

d. Insulators of the pin type for 50,000-volt circuits, and of the suspension type for 50 to 100,000-volt circuits, were perfected. This provided for increased reliability for ordinary service and the factor of safety during lightning storms.

DEVELOPMENT OF HIGH VOLTAGES FOR ELECTRIC RAILWAYS.

| Contact line. | | | Transmission line. | | |
|---|---|---|---|---|---|
| Year. | Direct-current voltage. | Name of railway. | Three-phase voltage. | Location or name of line. | No. of miles. |
| 1880 | 250 | Siemens at Berlin | | Exhibition | 1 |
| 1888 | 450 | Union Passenger Ry | | Richmond, Virginia | 3 |
| 1894 | 500 | Norwich Street Ry | 2,500 | Taftsville, Connecticut | 4 |
| 1895 | 550 | Lowell & Suburban | 5,500 | Lowell, Massachusetts | 15 |
| 1895 | 550 | Portland General Electric | 6,000 | Portland, Oregon | 13 |
| 1896 | 550 | Buffalo Ry. Company | 11,000 | Niagara-Buffalo | 21 |
| 1897 | 600 | Twin City Rapid Transit | 13,000 | Minneapolis-St. Paul | 9 |
| 1898 | 600 | Los Angeles Ry | 33,000 | Redlands, California | 75 |
| 1904 | 600 | Butte, Montana | 55,000 | Helena-Butte | 65 |
| 1906 | 600 | Rochester, New York | 66,000 | Niagara Falls | 165 |
| 1908 | 600 | Grand Rapids, Mich | 110,000 | Grand Rapids, Michigan | 50 |
| 1909 | 600 | Several. Denver | 100,000 | Central Colorado Power | 200 |
| 1910 | 600 | Several. Toronto | 110,000 | Niagara-Toronto, etc | 180 |
| 1911 | | | 125,000 | Commonwealth, Michigan | 100 |
| 1908 | 1200 | Indianapolis & Louisville | d. c. | Indianapolis-Louisville | 20 |
| 1911 | 1500 | Piedmont & Northern | 100,000 | Southern Power Co., N. C. | 140 |
| 1906 | 2000 | European, see Chapter IV | d. c. | Mozelle-Maizieres, France | 9 |

| Year. | Three-phase voltage. | Name of railway. | Three-phase voltage. | Location or name of line. | No. of miles. |
|---|---|---|---|---|---|
| 1896 | 500 | Lugano Street Ry | 500 | Lugano, Italy | 4 |
| 1899 | 750 | Burgdorf-Thun Ry | 16,000 | Switzerland | 30 |
| 1902 | 3,000 | Valtellina Ry | 20,000 | Northern Italy | 46 |
| 1903 | 11,000 | Zossen experiment | 11,000 | Berlin, Germany | 15 |
| 1909 | 6,000 | Geat Northern Ry | 33,000 | Cascade Tunnel, Washington | 30 |

DEVELOPMENT OF HIGH VOLTAGES FOR ELECTRIC RAILWAYS.

Continued.

| | Contact line. | | Transmission line. | | |
|---|---|---|---|---|---|
| Year. | One-phase voltage. | Name of railway. | Three-phase voltage. | Location or name of line. | No. of miles. |
| 1904 | 2,200 | Schenectady Ry | 22,000 | Ballston Division | 16 |
| 1904 | 3,300 | Indianapolis & Cincinnati | 33,000 | Indianapolis | 41 |
| 1906 | 6,600 | Spokane & Inland | 45,000 | Spokane-South | 50 |
| 1907 | 11,000 | Erie R. R | 60,000 | Rochester-Mt. Morris | 154 |
| 1908 | 11,000 | NewYork, NewHaven & Hartford | 11,000 | Woodlawn-Stamford | 22 |
| 1909 | 12,000 | French Southern or Midi | 60,000 | France | 50 |
| 1910 | 15,000 | Bernese Alps R. R | 60,000 | Switzerland | 60 |
| 1911 | 18,000 | Swedish State | 80,000 | Norwegian frontier | 70 |

**Voltages required** for transmission lines in railway work may be determined mathematically, but this is largely a matter of experience, and requires a knowledge of the important variables which affect capacity, losses, cost of equipment, and operating results.

Cross-sectional area of copper line is reduced 75 per cent. when the voltage is doubled, and therefore the higher practical voltages would be used to reduce the cost and loss, were it not that operation becomes more dangerous, and that insulation for generators, transformers, transmission lines and switches becomes more expensive.

Standard voltages used for common transmission lines in railway work are 6600, 13,000, 33,000, and 66,000. Generator and also contact line voltages seldom exceed 12,000 volts. Transmission lines use less than 1000 volts per mile of line.

## LAWS GOVERNING TRANSMISSIONS.

**Laws governing transmissions** are stated briefly:

a. With unit energy transmitted, the voltage and current generated will vary inversely.

b. With unit work done, unit loss in line, and fixed voltage at the terminals of the line, the weight of copper will vary as the square of the distance; its cross-section will vary directly as the distance; and the weight of copper will vary inversely as the square of the voltage at the terminals of the line.

c. With unit cross-section, the distance over which a given amount of power can be transmitted will vary as the square of the voltage.

d. With unit weight of copper, unit amount of power transmitted, and unit loss in distribution, the distance over which power can be transmitted will vary directly as the voltage generated.

**Kelvin's Law** which governs transmissions is this:

The annual cost due to line loss and interest charges should be equal; or the interest should equal the loss. Stated in another way: "The sum of the annual cost of the energy lost in the line and the annual cost of interest and depreciation should be a minimum." A consideration of the variable portions of the two sets of costs greatly simplifies the calculations on the most economical loss and investment. This subject is treated at length in many electrical text-books.

## IMPEDANCE AND RESISTANCE.

**Line Losses** are caused by resistance, but the drop in voltage in an alternating-current line is a function of the reactance. The effective resultant is called the impedance. In electric circuits impedance, and not the ohmic resistance only, must be considered. With alternating current the impedance of a copper transmission line is about 50 per cent. higher, and of steel rails is 600 to 800 per cent. higher, than with direct current; but the current itself is smaller.

Losses, in watts, equal the product of the resistance of the wires and the square of the current in the wires. The energy loss is transformed into heat. The drop in the line, in volts, is the product of the line resistance or impedance and the current.

Cycles affect the loss of voltage in transmission lines, and in copper and third-rail contact lines. The higher the number of cycles used, the greater is the impedance to the flow of current. With 60 cycles, the impedance is so high that this frequency is not used in electric railroading.

**Resistance of copper wire,** in ohms, is found by multiplying the resistance, K, of 1 foot of copper wire, 1 circular mil in diameter by the length of the wire in feet and dividing the product by the number of circular mils. $K=10.35$ ohms at 68° F., or 20° C., and increases 0.4 per cent. per degree C. Every third larger sized wire has twice the cross-section, twice the weight, and one-half the resistance.

**Heating of wires** must be considered. For a given resistance the heating effect varies as the square of the current. With fluctuating loads, the heating effect varies as the root-mean-square of the currents.

**Voltage drop** or voltage loss in line affects motor characteristics, drawbar pull, speed, and heating. An average contact line loss of 10 per cent., and a maximum of 20 per cent., are usually provided for direct-current and single-phase work. These losses must be much smaller in three-phase contact lines, for a 10 per cent. loss in voltage causes a 19 per cent. decrease in the drawbar pull of the motor.

IMPEDANCE VALUES OF SINGLE-PHASE LINES.

| No. and wt. of rails. | No. and size of trolleys. | Impedance, total in ohms per mile. 25 cycles. | 15 cycles. | Rail current. | Notes. |
|---|---|---|---|---|---|
| 8-100 lb .... | 4-0000 | .165 | .112 | .75 | With two 00 feeders. |
| 8-100 lb .... | 4-1000 | .189 | .130 | .75 | Without feeder. |
| 4-100 lb .... | 2-0000 | .310 | .220 | .58 | Without feeder. |
| 2-100 lb .... | 1-0000 | .553 | .396 | .40 | Without feeder. |
| 2-100 lb .... | 1-000 | .600 | .425 | .40 | Without feeder. |
| 2-100 lb .... | Not any. | .030 | .020 | .40 | A. c. resistance only. |
| 2-100 lb .... | Not any. | .025 | .... | .58 | A. c. resistance only. |
| 2-100 lb .... | Not any. | .080 | .048 | 1.00 | A. c. resistance only. |
| 2-100 lb .... | 1-000 | .047 | .028 | 1.00 | A. c. reactance only. |
| Not any..... | 1-0000 | .026 | .026 | 1.00 | A. c. resistance only |
| Not any..... | 1-000 | .470 | .... | .... | Impedance. |
| Not any..... | 1-0000 | .400 | .... | .... | Impedance. |

Data which do not specify the relative current in trolley and rail are not valuable.

*Copley's* measurements, given in Transactions, A. I. E. E., July, 1908, page 1171, are based on height of trolley of 22 feet, double catenary, 0000 rail bonds, and 60 to 70 per cent. power-factor.

*Rosenthal*, in "Transmission Calculations," has furnished other tables. See also *Dawson*, "Electric Traction for Railways," page 451; *Parshall and Hobart*, "Electric Railway Engineering," page 283; *Murray*, A. I. E. E., April, 1911, p. 751.

Impedance for other sizes of rail can be readily computed. The relative impedance at 25 and at 15 cycles should be as the square roots of the cycles, or as 1.29 to 1.00.

The steel catenary or messenger cable in parallel with the trolley reduces the above impedance values about 10 per cent.

The ratio of impedance to direct-current resistance of trolley wire, at 25 cycles, is 1.5 and the ratio for rails is about 6.0, but the current in the rails is small.

The resistance to direct current of two 100-pound steel rails is .03 ohms per mile.

## TRANSMISSION LINE ENGINEERING.

A clear understanding of the real problem involved in a transmission line must first be obtained. The extent of each item forming a part of a problem can be studied by means of an outline of the financial, technical, constructive, and operating features which are involved. Instead of an extended treatment of the subject, an outline frequently used by the writer in his work, one suitable for general consideration, is presented on the next page.

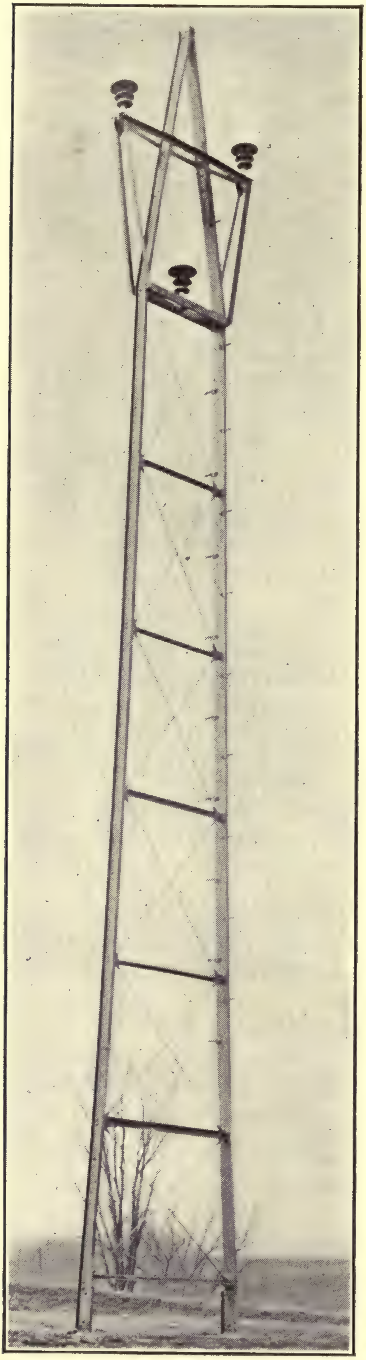

FIG. 172.—EXAMPLE OF FLEXIBLE STEEL TOWER FOR TRANSMISSION LINE. Eight-inch channels. Pin type insulators.

## OUTLINE FOR STUDY OF TRANSMISSION LINE ENGINEERING.

**Financial Basis:**

Earnings, present and ultimate conditions, effect on smaller undertakings, and effect on economy of plants.

Value of energy cost per kw-hr. transmitted, total cost of energy delivered. Competition and reputation; duplication of lines, voltage regulation.

**Electrical Energy:**

Present and future load; power factor and load factor.

**Location:**

Accessibility of locality, geography and elevations, freight charges, frequency of electric storms, precipitation, right-of-way and terminals, rivers, valley, swamp, lakes, special span constructions, franchise and municipal restrictions, crossings over steam railroads.

**Voltage and Cycles:**

Length of line, amount of load, type of insulator, protection of the public, separation of wires, inductive effect on line, impedance constants and losses, effect on cost of all equipment.

**Materials Available:**

Conductor: Aluminum or copper, cross-sectional area, stranding, mechanical strength, electrical resistance.
Poles: Wood or concrete; kind and character, cutting and sap, life and treatment, length and body.
Towers of Steel: Frame or pipe, angle or channel, two, three, or four legs.
Insulators: Porcelain, glass, pin types, 2 to 5 shells; steel or wood pins; disk, cone, and suspension types.

**Specifications for Materials:**

Quantity, quality, details of design, tests for acceptance.

**Results to be Anticipated:**

Guarantees, limitations, lack of funds, local conditions.

## INSULATORS.

**Insulators** for high voltage lines are made of porcelain. This is the only material which is adequate. Best clays are selected, great skill is used in manufacture, and in burning. By design, porcelain is not utilized to carry tensile stresses. In compression its strength is 16,000 to 20,000 pounds; in shear, 2400 to 2700 pounds; in tension, 650 to 3300 pounds per square inch.

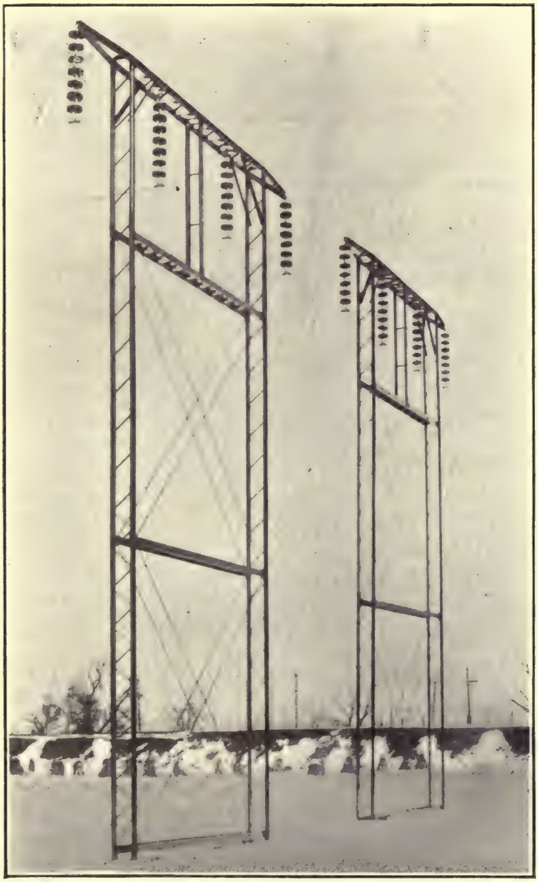

FIG. 173.—EXAMPLE OF FLEXIBLE STEEL TOWER FOR TRANSMISSION LINE. Latticed angles. Suspension type disk insulators.

Pin type insulators usually consist of 3 or more shells or pieces per insulator, mounted on one pin. The malleable iron pin has replaced the wooden pin, which in time was "digested" by static currents.

Suspension type insulators were first used in 1907. They have long and well-interrupted insulating surfaces to limit the surface leakage.

Several 20,000 to 25,000-volt disks or cones are suspended in a series, to insulate for any potential used.

Advantages of suspension type insulators: Torsional strains on the cross arms are decreased, but cross arms must be longer, and torsional stresses on the towers are increased. Flexibility is obtained to reduce the mechanical stresses. Cost of high-voltage insulators is increased. Factors of safety are raised in power transmission.

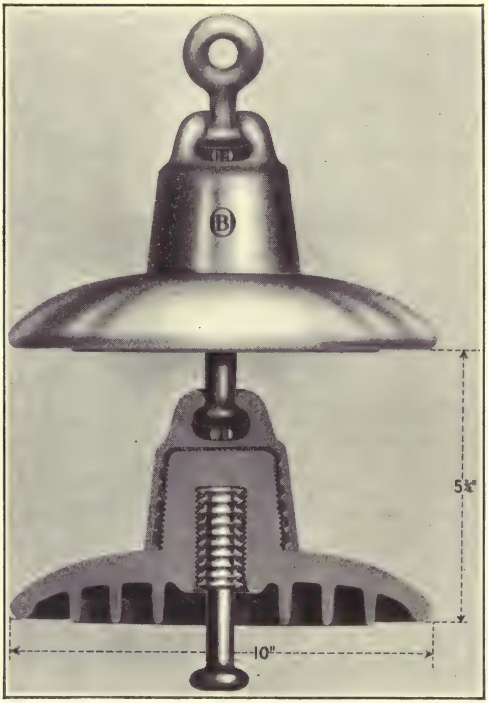


Fig. 174.—Two 25,000-volt Units of a Suspension Type Insulator.

The pin type insulator gives fair results up to 50,000 volts. The suspension type is now practically standard above 50,000 volts. In either case, an overhead ground wire is used, to assist in preventing the puncture of insulators by lightning, except on the Commonwealth Power Company and Grand Rapids-Muskegon, Michigan, transmissions, using 125,000 and 110,000 volts.

## DATA ON IMPORTANT HIGH-VOLTAGE TRANSMISSIONS.

| Name of transmission company. | Length miles. | Kilowatts delivered. | Voltage on lines. | No. of cycles. | Year built. |
|---|---|---|---|---|---|
| Connecticut River Power Company, Vernon, Vt.. | 66 | 15,000 | 66,000 | 60 | 1908 |
| Hudson River Electric Power Co., Glen Falls, N. Y.. | 18 | 5,000 | 44,000 | 38 | 1901 |
| Schenectady Power Company | 20 | 12,000 | 32,000 | 38 | 1909 |
| Niagara, Lockport & Ontario Power Company | 160 | 15,000 | 60,000 | 25 | 1906 |
| Toronto & Niagara Falls Power Company | 180 | 10,000 | 60,000 | 25 | 1907 |
| Canadian Niagara Falls Power Company | 15 | 82,500 | 62,500 | 25 | 1905 |
| Electrical Development Company, Niagara, Ontario. | 80 | 95,000 | 60,000 | 60 | 1909 |
| Buffalo, Lockport & Rochester Ry.; distribution from Niagara Falls. | 20 | 15,000 | 60,000 | 25 | 1895 |
| Hydro-electric Power Commission of Ontario (290 miles of towers). | 180 | 40,000 | 110,000 | 25 | 1910 |
| Shawinigan Water and Power Company | 80 | 50,000 | 56,000 | 30 | 1903 |
| Hamilton Cataract and Power Company | 40 | 25,000 | 45,000 | 66 | 1909 |
| Winnipeg Electric Ry. Company | 65 | 22,500 | 60,000 | 60 | 1904 |
| Rochester Ry. and Light Company | 30 | 8,000 | 57,000 | 25 | 1907 |
| Pennsylvania Water and Power Company, McCalls Ferry, Pennsylvania. | 40 | 30,000 | 70,000 | 25 | 1910 |
| Southern Power Company, Charlotte, North Caro- | 55 | 50,000 | 45,000 | 60 | 1907 |
| lina; 1230 miles of tower line | 240 | 80,000 | 100,000 | 60 | 1910 |
| Grand Rapids-Muskegon Power Company, Croton to | 40 | 8,000 | 72,000 | 30 | 1903 |
| Grand Rapids. | 50 | 10,000 | 110,000 | 30 | 1908 |
| Indiana & Michigan Electric Company | 50 | 15,000 | 47,800 | 60 | 1909 |
| Southern Wisconsin Power Company, Kilbourn, Watertown, Milwaukee. | 111 | 6,000 | 40,000 | 25 | 1909 |
| La Crosse Water Power Company, Wisconsin | 47 | 4,800 | 46,000 | 60 | 1909 |
| Great Northern Power Co., Duluth | 14 | 10,000 | 60,000 | 25 | 1910 |
| St. Croix Falls Improvement Company, Minneapolis Taylor's Falls. | 41 | 20,000 | 50,000 | 60 | 1907 |
| Northern Colorado Power Company, Denver | 126 | ......... | 66,000 | ....... | 1909 |
| Central Colorado Power Company, 430 miles of lines. | 153 | 12,300 | 100,000 | 60 | 1909 |
| Telluride Power Company, Provo, Utah | 55 | 20,000 | 44,000 | 60 | 1898 |
| Helena Power Transmission Company | 57 | 4,000 | 57,000 | 60 | 1900 |
| East Helena-Anaconda | 80 | 20,000 | 70,000 | 60 | 1908 |
| Great Falls Power Company, Great Falls-Anaconda | 150 | 30,000 | 100,000 | 60 | 1910 |
| Spokane & Inland Empire R. R. Company | 100 | 40,000 | 66,000 | 60 | 1907 |
| | | | 50,000 | 25 | 1909 |
| Washington Water Power Company, Spokane 450 | ......... | 20,000 | 63,000 | 60 | 1902 |
| Puget Sound Power Company, Tacoma-Seattle | 80 | 30,000 | 60,000 | 60 | 1903 |
| Seattle-Tacoma Power Company | 110 | 21,000 | 60,000 | 60 | 1898 |
| Northern California Power Company | 60 | 10,000 | 60,000 | 60 | 1909 |
| Great Western Power Company, Big Bend-Oakland. | 154 | 40,000 | 100,000 | 60 | 1909 |
| Sierra & San Francisco Power Company, 1400 of lines. | ......... | 90,000 | 104,000 | 60 | 1908 |
| California Gas and Electric Corporation, Colgate to | 117 | ......... | ......... | 60 | |
| Mission San Jose: Electra to Oakland. | 145 | ......... | ......... | 60 | |
| Pacific Light & Power, Kern River, Los Angeles | 117 | 30,000 | 75,000 | 50 | 1908 |
| Southern California Edison Company | 81 | 3,000 | 33,000 | 50 | 1898 |

STEEL TOWERS FOR TRANSMISSION LINES.

| Name of power transmission. | No. and size of conductors. | Kilo-volts. | No. of arms. | Spread of wires. | Type and parts per insulator. | Normal length of span. |
|---|---|---|---|---|---|---|
| Schenectady Power | 6–000 & G | 32 | 3 | 17′–0″ | Disk, 2 | 550′ |
| Niagara, Lockport & Ontario | 3–00 | 60 | 1 | 7′–0″ | Pin, 3 | 550 |
| Ontario Hydro-electric | 6–0000 & G | 110 | 3 | ........ | Susp., 8 | 550 |
| Southern Power, N.C | 6–00 & 2G | 100 | 6 | 6′–0″ | Disk, 4 | 600 |
| Grand Rapids-Muskegon | 3–2 | 110 | 3 | 8′–0″ | Disk, 5 | 528 |
| Commonwealth, Michigan | 3–2 | 125 | 3 | 6′–0″ | Disk, 8 | ........ |
| Southern Wisconsin | 6–0 & G | 40 | 3 | 6′–0″ | Disk, 3 | 528 |
| Milwaukee Electric | 6–0 & G | 40 | 3 | 6′–0″ | Disk, 3 | 528 |
| La-Crosse, Wisconsin | 3–2 & G | 46 | 3 | 6′–0″ | Pin, 4 | 480 |
| St. Croix Falls-Minneapolis | 3–0000 & G | 50 | 1 | 7′–0″ | Pin, 3 | 440 |
| Great Northern, Duluth | 6–00 | 60 | ...... | ........ | Pin, 3 | 400 |
| Winnipeg Electric Ry | 6–00 | 60 | ...... | 6′–0″ | Pin. | 450 |
| Telluride (Colorado) Power | ................ | 44 | 1 | 12′–0″ | Susp. | ........ |
| Central Colorado Power | 3–0 & 2 G | 100 | 1 | 10′–4″ | Susp. 4 | ........ |
| Northern Colorado Power | ................ | 66 | ...... | ........ | ........ | ........ |
| Utah Light & Power | 6–0 & G | 40 | ...... | ........ | ........ | 600 |
| Great Falls Power Co | 6–0 & 2 G | 100 | 2 | 10′–4″ | Susp. 6 | 600 |
| Anaconda Copper Extension | 3–0 & G | 100 | ...... | 10′–4″ | Susp. 6 | 600 |
| Washington Water Power, Spokane | 6–000 & G | 60 | ...... | ........ | ........ | ........ |
| Great Western, San Francisco | 6–000 & G | 100 | ...... | 13′–0″ | Susp. 4 | 750 |
| Sierra and San Francisco | 3–00 | 104 | ...... | 8′–0″ | Susp. 5 | 800 |
| Los Angeles, Kern River | 9–0000 | 75 | 2 | 6′–0″ | Pin, 4 | 542 |
| Arizona Power M. & M | 6–0 | 52 | 3 | 10′–0″ | Susp. | ........ |
| Guanajuato, Mexico | 3–1 & G | 60 | 2 | 6′–0″ | Pin, 3 | 440 |
| Nexaca, Mexico | 6–000 & G | 60 | 1 | 6′–0″ | Pin, 3 | 500 |

Conductors are of copper except in the Southern Wisconsin; Ontario Hydro electric Power; Niagara, Lockport & Ontario.

G signifies a protecting cable, usually of 7-strand steel, strung over the tower.

## STEEL TOWERS FOR TRANSMISSION LINES.

| Name of transmission. | Name of manufacturer | Height of tower. | No. of legs. | Width at base. | Wt. of tower lb. | Data on posts. | Kind of steel. |
|---|---|---|---|---|---|---|---|
| Schenectady Power | Milliken | 48–71 | 4 | 17′–7″ | 4350 | | Gal. |
| Niagara, Lockport & Ontario. | Aermotor | | 4 | 6′–0″ | | 2½x2½x¼ L | Gal. |
| | Archbold B. | 45–50 | 4 | 6′–0″ | | | Plain. |
| Ontario Hydro-electric. | Canadian B. | | 4 | 17′–0″ | 4000 | | |
| McCalls Ferry Power | | 40–60 | 4 | | | | |
| Southern Power, N. C. | Aermotor | 35 | 4 | | 2400 | | |
| | Aermotor | 40 | 4 | | 3080 | 3x3x3/16 L | Gal. |
| | Milliken | 50 | 4 | | 3500 | | |
| Grand Rapids-Muskegon | Aermotor | 40–53 | 3 | | 1700 | 3x3x3/16 L | Gal. |
| Commonwealth, Michigan | Aermotor | 45 | 3 | 12′x17′ | 1900 | | Gal. |
| Southern Wisconsin | Aermotor | 40 | 4 | 12′–0″ | | 3x3x1/4 | Gal. |
| Milwaukee Electric Ry. | Aermotor | 40 | 4 | 12′–0″ | | 3x3x1/4 | Gal. |
| St. Croix-Minneapolis | Archbold B. | 48 | 2 | 9′–0″ | 2150 | 9″–13¼ ch. | Plain. |
| Winnipeg Electric Ry. | | | | | 2250 | | |
| Central Colorado | Milliken | 44 | 4 | 13′x14′ | 2200 | L | Gal. |
| Telluride (Colorado) power | U.S.Wind. | 51–58 | 4 | 13′x11′ | | 4x4x1/4 L | Plain. |
| Great Falls Power & T. | Amer. Bdge. | | 4 | 13′–0″ | 2140 | | |
| Anaconda Copper | Aermotor | | | 10′–0″ | | | |
| Washington Water Power, | U.S.Wind. | 50–68 | 4 | 16′–0″ | | 4x4x1/4 L | |
| Great Western, San Fran. | Milliken | 61 | 4 | 17′–0″ | 3800 | | |
| Sierra & San Francisco | | | 4 | 15′–0″ | 3400 | | |
| Los Angeles, Kern River. | U.S.Wind. | 54–60 | 4 | 12′x13′ | 4250 / 4950 | 4x4x5/16 L | Gal. |
| Arizona Power M. & M. | U.S.Wind. | 33–42 | 4 | 9′–0″ | 1125 | 2¾x2¾x1/8 L | Gal. |
| Guanajuato, Mexico | Aermotor | 41–47 | 4 | | | | Gal. |
| Nexaca, Mexico | U.S.Wind. | 26–42 | 3 | 14′–0″ | | 3x3x¼ | Gal. |

Height of tower is measured from the connection near the surface of the ground to the lowest transmission cross arms. The steel work below the ground is generally less than one-seventh of the height to the upper cross arm.

### CONTACT LINES.

**Voltages** are usually 600 for third-rail lines, and 600, 1200, 3300, 6600, and 11,000 volts on overhead trolley contact lines. The current is reduced proportionally as the voltage is increased.

**Design of contact lines** for electric railway train service involves these essentials: Mechanical strength, electrical carrying capacity, collection of current, and adequate support or suspension.

a. **Mechanical strength** is gained by the use of 3/0 and 4/0 grooved-section, hard-drawn copper wire. Smaller sizes are not used in railroading because of the danger from breakage after pitting, arcing, hard spots, crystallization, and wear. A 4/0 wire has a tensible strength of 7000 pounds, or 5000 at joints, and a working tension of 2000 pounds.

b. **Electric carrying capacity** is generally many times larger than necessary to prevent overheating of conductors.

c. **Collection of current from contact lines** requires that the contact point, line, or surface be ample to prevent arcing.

**Trolley wheels,** cylinders, or rollers, without seriously burning the wire and wheel, collect 1200 amperes at 5 m. p. h; 600 amperes at 15 m. p. h.; 350 amperes, at 40 m. p. h.; and 200 amperes at 60 m. p. h., the latter with catenary construction. New cooled contact points are continually negotiated. A pressure of 30 to 40 pounds is required between the wheel and the wire, for speeds of 50 to 60 m. p. h. Wheel collectors are seldom used in electric train service. When a trolley wheel jumps off the contact line at high speed, the overhead work suffers; and at low speed the drawbars are jerked out.

**Third-rail contact shoes,** of malleable iron, at 30 m. p. h., readily collect 2200 amperes, and at 60 m. p. h., 600 amperes.

**Pantographs** with a wide sliding shoe are also used for the collection of heavy current from an overhead line. Brooklyn Bridge Railroad used pantographs before the third rail was installed. Small pantographs are used on locomotives to reach overhead third rails in switching yards. Three-phase and single-phase high-speed railroad trains require pantographs. In train service, contacts are usually in parallel.

**Bows** are a modification of the pantograph, in which either a cylindrical roller, or a metallic contact shoe of iron or aluminum, shaped as a bow, is placed between two light-weight supporting pipes. Bows are made in many styles but they are lighter than pantographs. They are often compounded, so that the lower part makes the large variations in elevation, while the small bow, mounted upon the long heavy frames, easily follows the minor variations in elevation.

**Height of contact wire** has a great deal to do with the operation of a trolley, pantograph, or bow-collector. European roads place the trolley wire 16 to 17 feet above the rails. American roads place the trolley 22 to 24 feet above the rail. A small change in track alignment makes a wide lateral change at the contact; and trouble seems to vary about as the square of the height of the trolley wire above the rail.

**The mechanics of current collection from overhead lines** is this: A point must be kept in contact with a line. This contact point travels at speeds up to 68 m. p. h. or 100 feet per second. During this second, the contact wire varies 2 to 3 inches in its elevation. The forces acting on the pantograph or bow, to keep the point and the wire in contact, vary as the mass and the square of the velocity. Therefore, the ideal bow or pantograph is one with minimum weight. The velocity referred to is the rate of change of the contact point in its vertical position. The ideal line is thus one in which the wire does not sag. The wire supports between the brackets or bridges are placed at short intervals to prevent a rapid change in the vertical position, for these changes must be followed by the bow or pantograph. This involves a taut line, which requires infinite tension. Since wires stretch, gradually slacken at

curves, and vary greatly in length with the temperature, an automatic adjustment in the tension by weights or springs is desirable. On many European roads the trolley is anchored at one end and attached at the other end to a weight, hung over a pulley, of 2000 pounds per mile of line.

The contact line support must be *flexible* in order to prevent localization of the contact pressure of the pantograph at the supporting points. Intensity of pressure or of blows must be avoided, to reduce the work of destruction and the maintenance expense. A moving contact follows a *rigid* line, with destructive chattering and vibration.

On a 300-foot span, a 5-point suspension, two very light multiple contacts, and small pressure from a bow, works out about as well as a 20-point suspension, one contact, and heavy pressure from a pantograph.

A large number of types of catenary suspended line have been tried by the Pennsylvania Railroad. Elec. Ry. Journ., Dec. 12, 1908, p. 1546.

**Two overhead trolley contact wires** are required with 3-phase motors. There is a difference of potential of 3000 to 6000 volts between the wires. Two overhead wires have the following **disadvantages**:

Two contact wires must be supported and insulated from each other, and from their mechanical supports.

Catenary line supports parallel to the two trolleys, if used, would make an expensive construction.

Danger exists, due to the complication and to the short distance between the two wires. (On the three-phase European roads, real high-speed service is not attempted.) The use of 6000 or 11,000 volts between the two wires would thus be at a disadvantage for ordinary, 50 to 60 m.p.h. railroad traffic.

Cost of supports, insulators, switch work, labor, and copper, is about twice that for the single contact line.

Maintenance cost is greater than with a single contact line.

Poles and overhead construction are heavier, because the weight to be supported and the strains to be balanced are doubled.

Weight of two wires for the 3000- or 6000-volt, three-phase system is much greater than that of one wire for the single-phase system at 11,000 volts, because the current per wire is higher for the low voltages.

**Current per wire,** for an ordinary railway train, or about 1000 kv-a., is given in the following table.

AMPERES PER CONTACT LINE, 1000 KV-A., 1 AND 3-PHASE SYSTEM.

| Potentials used. | One-phase, 1-wire system. | Three-phase, 2-wire system. |
|---|---|---|
| 3,000 volts. | 333 amperes. | 192 amperes. |
| 6,000 volts. | 166 amperes. | 96 amperes. |
| 11,000 volts. | 98 amperes. | 52 amperes. |

The use of 11,000 volts has been well standardized by single-phase railroads and, except for Great Northern Ry., 3000 volts is used by all three-phase railroads.

Contact line losses are higher for the low-voltage three-phase system.

Pounds of copper required for the three-phase system are 14 per cent. greater than for the single-phase, for same voltage.

**One trolley or two trolleys,** about 36 inches apart, must be used in heavy electric railroading. The subject deserves consideration in view of the cost, the complication, and the danger.

"One object of all engineering is to dispense with complications and unnecessary parts, unless some paramount advantage is gained by complication. Everything points to the ultimate adoption of a single working conductor wherever heavy electric railroading is to be expected. There are complications enough with only one working conductor at points of limited clearance to convince railway engineers of the undesirability of increasing the complications by the addition of another conductor."

"It is a vast problem to install, in a switchyard containing a maze of tracks, a system of electric power supply utilizing a single conductor. Imagine what is to be done to supply this yard with two overhead conductors in addition to the ground return. The great difficulty and the enormous complications in overhead construction in switching is one of the most serious handicaps of the three-phase system of traction." Steinmetz: General Electric Co., to A. I. E. E., June, 1905, page 516.

One great problem in electric traction is the transfer of energy in large quantities, at high potentials, from an overhead contact line to a rapidly moving locomotive used on the main line or in freight switching yards. This transfer of energy is facilitated with one overhead contact line over each track. The cost of one or two overhead trolley wires is important, but simplicity and safety are paramount.

CONTACT LINES USED ON THREE-PHASE RAILROADS.

| Name of railway. | Diameter. | | Gage No. | Circular mils. | Normal span. | Height above rail. |
|---|---|---|---|---|---|---|
| | mm. | inches. | | | | |
| Burgdorf-Thun | 8.0 | .315 | 0 | 100,000 | 115′ | 17′–0″ |
| Valtellina | 8.0 | .315 | 0 | 100,000 | 83 | 17′–0″ |
| Simplon, two | 8.0 | .315 | 0 | 200,000 | 85 | 17′–0″ |
| Giovi | 8.3 | .326 | 0 | 106,000 | 100 | 17′–0″ |
| Great Northern | 11.2 | .460 | 4/0 | 211,600 | 100 | 24′–0″ |

| Name of railway. | Voltage used. | Wire centers. normal. | Wire centers. curves. | Contactor type. | Span or brackets. | Speed m.p.h. |
|---|---|---|---|---|---|---|
| Burgdorf-Thun... | 750 | 36.0″ | ........ | Bow.......... | Bracket. | 24 |
| Valtellina........ | 3000 | 34.5 | 34.5″ | Pantograph.... | Both.... | 40 |
| Simplon.......... | 3000 | 39.0 | ........ | Bow.......... | Span.... | 43 |
| Giovi............ | 3000 | ........ | ........ | Pantograph.... | Span.... | 28 |
| Great Northern... | 6000 | 60.0 | ........ | Trolley wheels. | Both.... | 15 |

**Switchwork for three-phase overhead construction** is complicated at best, but not impracticable. Certain rules are to be followed:

One wire must not occupy such space that the collector can cause a short circuit to the other wire.

Two or more collectors may be used on a locomotive or along a motor-car train, but these must not cause a short circuit. In general it is not much more dangerous to use two collectors per train than one. Valtellina Railway uses two, 38 feet apart on motor cars, and 23 feet apart on locomotives.

If the two wires have unequal sags, bad alignment, or over- or under-separation, a foul will be caused by the action of the collectors in running above or at the side of one wire, or between them.

Mechanical contact must necessarily be continuous in switch work, either by dead or live wires. Collectors must not travel free in the air as in the case of a third-rail shoe.

Electrical circuits must be continuous; that is, power must be available at all times. Trains must be started at all switches. Breaks in the current will cause drawbars to be pulled out. Power to reverse must be available to prevent accident.

Separation of track sections, for the control of circuits, necessarily increases the complication.

## CATENARY CONSTRUCTION.

Suspension of a contact wire by hangers from a steel messenger cable, which has several times the strength of hard-drawn copper contact wire, is known as catenary construction The plan is used to obtain long spans, strength, safety, and a level contact wire. In detail:

Supports for the messenger cable are usually structural steel bridges for long spans, and wood or steel poles for medium spans.

Messenger cables made of double-galvanized plow steel of highest tensile strength are used, and spans of from 250 to 300 feet are easily carried. A 1/2-inch 7-strand cable has a minimum elastic limit of about 6000 pounds, which is 60 per cent. of its breaking strain.

Tensile strains in a suspended messenger or catenary cable are proportional to $WL^2/8D$, where W is the weight of the load in pounds per running foot (about 1 pound for 4/0 trolley, 1/2-inch messenger, and 15 feet between suspenders), L is the length of the cable span, in

feet, and D is the sag of the cable span, in feet. In case a support is broken, L is doubled and the strains are increased about 40 per cent. Coatings of ice 1/2 inch thick, and wind pressures of about 8 pounds per square foot must be considered.

Insulators for messenger cables are porcelain; for guys are of impregnated wood in series with porcelain. When the voltage is 6000, wood may be used in tension, but porcelain is always used in compression.

Suspenders are used between the messenger cable and the contact line. Suspender links should be flexible, to prevent arcing by the contactor, and bent, looped, curved, or coiled suspenders can be used as well as straight solid rods. Links must not be loose to wear, or contain cup-pointed set screws which cut the cable; and so bolted clamps usually connect the ends of the suspender to the cable and contact line. A horizontal spacing of clamps of 18 to 25 feet is common practice.

Contact lines are built of grooved copper wire, without or with a steel wire hung below and parallel to the copper wire. With the compound, or multiple catenary construction, great flexibility is gained by suspending the steel contact wire from the copper wire at points half way between the suspenders from the messenger. Brackets which support messenger cables are hinged, to allow slight vertical, and also some horizontal swing.

**Catenary construction for three-phase railways** should be similar to that of single-phase railways if speeds are to be high on the former. The necessity of insulating the catenary cables from each other, and from the supporting structure, is evident. Catenary cables, parallel to the contact line, have not yet been adopted by three-phase roads.

**Berlin-Zossen contact line** construction with three 11,000-volt wires in a vertical plane was a failure. The complication and cost were too great; yet there were no switches from the main line. The side pressure between the bows and the contact lines was very light.

**Valtellina Railway,** and **Great Northern Railway** trolley wires are usually supported, near each pair of poles, by two independent steel span cables, and the latter are spread about 39 inches. When brackets are used the two trolleys are supported from two independent steel span cables, spread about 13 inches, each cable supporting a trolley wire from an insulated hanger.

**Simplon terminal yard** construction is designed to support two trolleys from two cross-suspended wires stretched between light tubular steel supports. Vertical steel supports are in tripod form, and, where they straddle 6 tracks, a horizontal tie bar is placed between the upper ends of the tripods. The uprights are fixed to earth plates imbedded in two feet of concrete, and take up a very small portion of the way, give great stability, are cheap, and do not obstruct the view of signals.

**Simplon Tunnel** construction involves copper plated steel cross wires stretched between gun-metal studs grouted into the face of the tunnel, the cross wires being

insulated with common porcelain and drawn tight. The studs are 82 inches apart. The trolley wire is secured by means of ebonite-covered bolts to gun-metal cross bars, the ends of which are screwed into bell-shaped porcelain insulators, a layer of hemp and asbestos being interposed between the screws and the porcelain at each end.

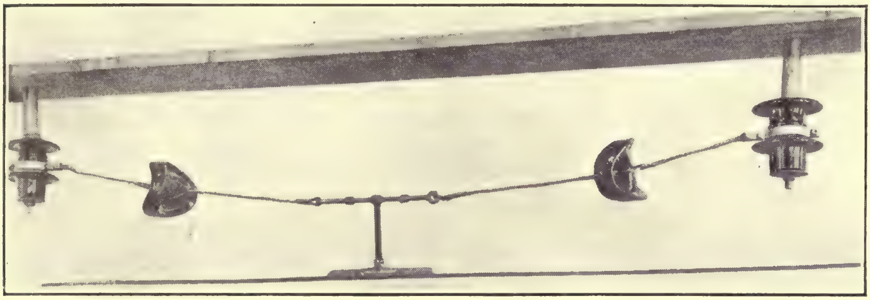

Fig. 175.—Great Northern Railway. Insulator Support in Concrete Roof of Tunnel, Parallel to the Contract Line.

These porcelain insulators are in turn screwed into gun-metal end caps with a layer of rubber, which is imposed to give elasticity to the whole insulator and thus to prevent a fracture. The insulators are tested to 40,000 volts, while the maximum working voltage is 3300.

Fig. 176.—Great Northern Railway, Cascade Tunnel Yards. View of Switchwork.

The tunnel line is 12 1/2 miles long. Power plants are placed at each end. Two trolley wires, each 100,000 cm., are used for each phase to avoid the handling of heavier wire in the tunnel. If one wire breaks or becomes defective it can be cut away or renewed with facility. The overhead wires are arranged in zigzag fashion, to equalize the wear along the collecting bow.

**Giovi Railway three-phase contact line** is suspended from two parallel catenary cables one meter apart. Flat suspender links are used. The catenary and contact wires are supported by long cantilevers made of two 6-inch I beams extending from heavy structural steel poles. Light gas pipe like that at the Simplon yards is not used. Hanger supports are clamped to the under flange of the cantilever I beams and grip a high-tension, horizontal, spool insulator which is cemented on a 1.5-inch iron pipe. The wire hangers are clamped to this insulator and to the contact line below. Each hanger has a pair of parallel-motion links, by which vertical flexibility is obtained. See photographs by Miller in Elec. World, Oct. 13, 1910, page 863.

**Syracuse, Lake Shore & Northern Railroad,** a double-track direct-current road between Syracuse and Oswego, N. Y., uses catenary construction for direct current. Bridges span the track at 300-foot intervals. These consist of two "A" frames, erected in concrete foundations, and connected by a 30-foot truss. Angle braces

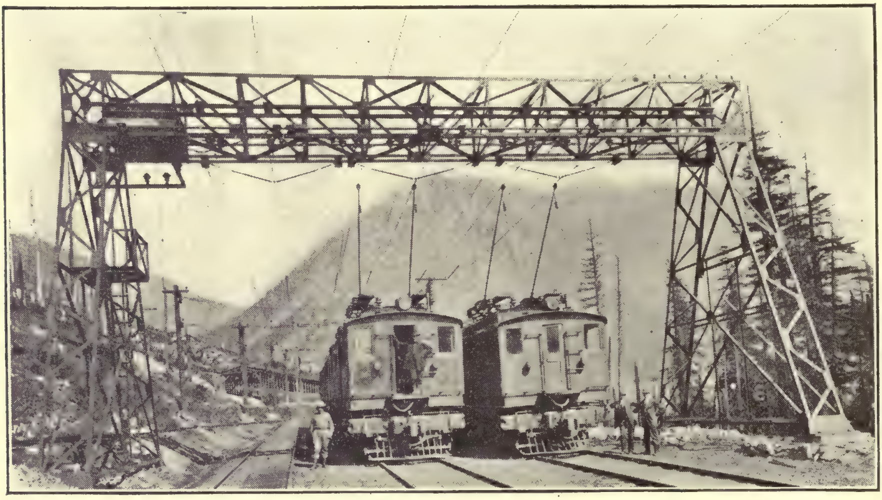

Fig. 177.—Great Northern Railway Anchor Bridge for Dead end of Catenary Line. Trolley poles and trolley wires over each locomotive are 6 feet apart.

connect the frames and trusses. Catenary construction consists of 7/16-inch galvanized steel strand supported by a 2-piece 22,000 volt-porcelain insulator. The sag is 6.5 feet at 100° F., and 5.5 feet at 20° F. The trolley is a No. 4/0 cable, supported by hanger rods every 10 feet horizontally. Their length varies from 4.5 to 77.5 inches. In 1909, additional catenary construction was erected and a 500,000-cm. copper feeder cable was used in place of the galvanized steel strand.

**Erie Railroad** catenary construction on a 37-mile, 11,000-volt, single-phase contact line between Rochester and Mount Morris, New York, was erected in 1906.

Steel side poles are used around extensive terminal yards. Chestnut poles are used on the main line. These vary in length from 35 to 55 feet, with an 8-inch top. The spacing is 120 feet. The pole brackets are of 3x3x108-inch "T" bars. The bracket insulators are double petticoat porcelain, 5 inches high. The messenger cable is of 7/16-inch galvanized steel strand, tested for 2250 pounds. Hangers are spaced 10 feet apart and consist of 5/8-inch rods. Trolley wire is No. 3/0. Pneumatically operated pantographs are used.

The conditions of service are severe, because the line work is badly maintained and because the steam locomotives of thru trains and all freight trains run on the track under the catenary. Trouble has been experienced in wind storms due to the wide swing of the trolley, also from chafing between the hangers and the messenger.

**New York, New Haven & Hartford** catenary line construction is used on 22 miles of the 4-track New York division between Woodlawn and Stamford. It was erected in 1906 for 11,000-volt single-phase service.

Anchor bridges used on the New York Division of the New Haven road are located about every two miles on straight track. The posts are 61 feet 10 inches on centers. The tracks are on 13-foot centers. The base is built up of plates and angles which rest on concrete pedestals. The latter are 8 feet deep, 7 feet 2 inches wide at the base, and 4 feet 6 inches wide at the top. The lower cord of the truss is 24 feet and

Fig. 178.—New York, New Haven and Hartford Railroad. Overhead Construction.

the trolley is 22 feet above the head of the rail. The bridges carry semiphores for each track, oil feeder circuit-breakers, trolley line circuit-breakers, lightning arresters, transformers, etc. See drawings in Elec. Ry. Journ., April 14, 1906.

Four-track bridges are used between Woodlawn and New Rochelle and 6-track bridges between New Rochelle and Stamford.

Steel bridges 300 feet apart carry a double-catenary suspension with two 9/16-inch, 7-strand galvanized steel cables, which have a 6-foot sag between bridges.

Trolley wire of 4/0 copper is suspended from the two catenary cables, being placed at the lower apex of an equilateral triangle. This plan of suspension prevents side motion of the trolley wire when the pantograph is swayed by changes in track alignment, but it provides a very rigid and heavy construction for the high-speed train service.

In operation, the pressure from the heavy pantograph which is used formed hard spots in the line, and gathered up the slack in the copper in kinks at hangers. The copper wire wore rapidly at the suspension point, and fractured. In 1908 there was added a horizontal, grooved, steel contact wire supported by 9-ounce clips from the former solid copper contact wire, at mid-points between messenger hangers.

The steel does not expand or kink like copper. The tension in this steel wire does not exceed the elastic limit of the steel at low temperatures.

The maintenance expense per mile of line and per passenger train-mile is reported to be decidedly less for the catenary construction than for the third-rail construction used by the Hew Haven for one-third of its run.

**Harlem River catenary construction,** for 62 miles of freight yards, embodies towers along each side of the tracks on about 250-foot centers, which towers are cross connected by 7/8-inch steel cable, which usually spans 6 to 9 tracks. Suspenders are on 10-foot centers and support a porcelain insulator, below which are suspenders for a 2/0 steel contact line. Two additional cross catenary spans connect the towers to steady the contact line. There is no catenary parallel to the contact line. See drawings by Murray, A. I. E. E., April, 1911.

FIG. 179.—NEW YORK, NEW HAVEN AND HARTFORD RAILROAD OVERHEAD CONSTRUCTION.

**New York, West Chester and Boston** 4-track catenary construction embodies steel bridges on 300-foot centers, 7/8-inch main messenger strand, from which 5/8-inch messenger strand is suspended at two points 50 feet from each tower. Hangers are placed on 10-foot centers and support a 4/0 copper wire and a 4/0 steel contact wire. The four messenger cables are cross-connected by 41-foot 3-inch, 5.5-pound per foot I-beams, at points 50 feet each side of each tower.

**Boston and Maine** 4-track yard construction embodies two latticed steel towers at each side of the track, top connected by a 5/8-inch steel strand; a large sag; 5/16-inch soft steel strand suspenders; and insulators in the suspenders, below which is a 4/0 copper wire and a 4/0 contact wire. Between the insulator and the trolley a 5/8-inch horizontal cross-strand is connected to steady the 4 trolleys, the ends being connected to the two towers. The catenary, parallel to the trolley, usually extends from the insulator but on some of the work the catenary is omitted.

Boston and Maine 2-track construction embodies 300-foot spans, 5/8-inch steel

messenger strand, suspended from insulators clamped to the lower cord of the bridge truss, a 4/0 copper trolley wire and a 4/0 phono contact wire.

Catenary construction in the tunnel embodies a catenary suspension wire, 1/2-inch round rod suspended on 10-foot centers, at the bottom of which is a double hanger for two 4/0 contact wires.

CATENARY CONSTRUCTION DATA.

| Name of railway. | Type of support. | Span in feet. | Messenger cable diameter. | Hanger centers used. | Trolley wire No. | No. of tracks. | Catenary sag normal. |
|---|---|---|---|---|---|---|---|
| New Haven: | | | | | | | |
| 1906 | Bridge .. | 300 | 2–9/16″ | 10′ | 4/0 | 4 | 6′–3″ |
| 1908 | Bridge .. | 300 | 2–9/16″ | 10′ | 4/0 | 4 | 6′–3″ |
| 1910 | Arch.... | 300 | 4–1¼ | 10′ | 4/0 | 6 | 10′–0″ |
| Harlem Yards | Cable ... | 250 | 1–7/8″ | 10′ | 2/0 | 6 to 9 | .......... |
| N. Y. West. & Boston | Bridge .. | 300 | 1–⅞ & ⅝″ | 10′ | 4/0 | 4 | 8′–0″ |
| Boston & Maine | Bridge .. | 300 | 1–⅝″ | 10′ | 4/0 | 2 | 8′–0″ |
| New Canaan Branch | Bracket . | 150 | 1–7/16″ | 14′ | 4/0 | 1 | .......... |
| Grand Trunk | Bridge .. | 250 | 1–5/8″ | ........ | ........ | 1 to 8 | .......... |
| Erie R. R | Bracket . | 120 | 1–7/16″ | 10′ | 3/0 | 1 | .......... |
| Washington, Baltimore & Annapolis | Bracket . | 150 | 1–3/8″ | 16′ | 4/0 | 1 | ........ |
| Syracuse, Lake Shore & | Bridge .. | 300 | 1–7/16″ | 10′ | 4/0 | 2 | 6.5′@100° |
| Northern | Bridge .. | 300 | 1–3/4″ | 30′ | 4/0 | 2 | 5.5′@20° |
| Rock Island Southern | Bracket . | 150 | 1–7/16″ | 15′ | 4/0 | 1 | |
| Chicago, Lake Shore & South Bend | Bracket . | 167 | 1–8/16″ | 14′ | 4/0 | 1 | |
| Peoria Ry. & Terminal | Span.... | 100 | .......... | 14′ | 3/0 | 1 | 6to10 |
| Colorado & Southern | Bracket . | 120 | 1–11/16″ | 10′ | 4/0 | 1 | .......... |
| Galveston-Houston | Bracket . | 150 | 1–7/16″ | 15′ | 4/0 | 1 | 13′–0″ |
| Seattle & Everett | Bracket . | 140 | 1–7/16″ | 20′ | 4/0 | 1 | .......... |
| Visalia Electric | Bracket . | 120 | 1–7/16″ | 11′ | 4/0 | 1 | 1′–0″ |
| Seebach-Wettingen | Bracket . | 328 | 1–7/16″ | 16′ | 1/0 | 1 | .......... |
| Midland, England | Bridge .... | ........ | ........ | ........ | 3/0 | 2 | .......... |
| London, Brighton & South Coast | Bridges . | 180 | 2–3/8″ | 10′ | 4/0 | 2 | 5.0′@50° |

Suspenders from single messenger cables usually vary in length from 6 to 20 inches per span.

A copper contact wire is used in all the above cases, except for the 1908 New Haven work wherein a 4/0 steel contact wire was suspended from the copper wire. The New Haven, Seebach-Wettingen, Midland, Cologne-Bonn, Blankanese-Ohlsdorf, and London, Brighton & South Coast use a double catenary. Phono-electric contact wire is used on the Colorado & Southern, near Denver.

Grand Trunk uses two 300,000 cm. trolleys in the tunnel, attached to the tunnel shell at intervals of 12 feet.

Brackets are usually 2 1/4x2 1/4x5/16-inch, T-steel, 11 feet long.

Trolley tension is usually 2000 pounds and messenger tension is 2200 pounds.

## THIRD-RAIL CONTACT LINES.

American and European third-rail lines with length of track, number of motor cars, and location of third-rail were listed under "History of Electric Traction."

A conductor of large cross-section, one which was decidedly more substantial and which had more contact surface than the overhead copper trolley, is used to transmit and to deliver low-voltage currents.

The general characteristics of the electric roads which use what is now called the "third-rail system" are: A positive third-rail contact line, track rails for the return circuit, low voltage, large currents, direct current, for local and important traffic, or long-distance and light traffic.

Third rails were at first common track rails, but the rail section has been changed slightly in shape to suit the contact shoe, and the chemical composition of the steel has been purified to increase the conductivity, and modified to obtain a soft steel which wears slowly. The current carrying capacity and the resistance of a 100-pound steel rail, well bonded at joints, approximates that of a copper cable which has a cross-section of 1,000,000 circular mils.

**Overhead third-rail conductors** were tried by the Baltimore & Ohio Railroad at Baltimore in 1896, but were soon abandoned. An unyielding rigid contact was found to produce chattering and sparking.

The Buda-Pest Stadtbahn Aktien Gesellshaft, an underground road 2.4 miles long, uses two overhead contact rails attached to the roof of the tunnel for positive and return current, the current being collected by means of a rather flexible pantograph.

Overhead third-rail conductors are now used in freight switching yards, for terminals at Brooklyn, for the Steinway tunnel, etc.

**Third-rail voltage,** between the third-rail and the track rails is commonly 600 volts. This voltage does not produce objectionable leakage of electricity even when the third rail is covered temporarily with water. A man in normal, healthy condition will not be killed by the current which will pass from the third rail thru his body to the track rails or ground, from accidental contact. The danger from contact by workmen is much decreased, when 660 to 800 volts are used, if the third rail is protected by plank, terra-cotta, vitrified fibre, etc.

The use of 1200 volts on third rails increases the leakage materially. Accidental contact with a 1200-volt, direct-current, third-rail line is most dangerous to life. In mountain roads, where the fall of heavy wet snow often exceeds 12 inches in a few hours, the ordinary snow plow could not be used, because the third rail would be in the way; and even if the third rail were 4 feet away from the track rail it would still be in the way, and it would not be tolerated by railroad operators.

**Insulation** for third-rail supports at first was wood, boiled in paraffine. It wore and burned, and was discarded for reconstructed granite, which disintegrated. Porcelain has been adopted. The annual breakage from leakage, blows, rail movement, derailment, etc., is about 1 per cent.

Supports for third rails rest on the extended ties so that the track-rail and third-rail alignment remains in the same plane. Insulator supporting distances vary. New York Central uses 11-foot centers; Long

Island, Pennsylvania, and Michigan Central, 10-foot; other roads, 9- to 8-foot. The third rail is placed between the double tracks, to standardize and in order that the off-side may be used for the unloading of materials.

**Disadvantages of the third rail for railroads** are:

1. Danger is increased for track employees, trespassers on right-of way, passengers at stations, trainmen at shunting yards, and teams at freight terminals. The third rail is located alternately on different sides of the track to suit cross-overs, curves, and physical restrictions; and as a result its location is uncertain and danger exists, as the rear brakeman or guard who is sent back on the run at night to protect the train soon finds. The coupling of cars and the crossing of yards in a hurry, are made more dangerous. Risk is necessary during the unloading of freight at sidings, the quick handling of materials, and the renewals of track, particularly at night. Wrecks become more dangerous. Derailment of a train may be followed by fires from electric power. Replacement of rails requires additional time for emergency repairs.

2. Restrictions are made on clearance of foreign cars, damaged cars, snow plows, and wrecking cranes, particularly at tunnels and bridges. The distance from the third rail to the track rail should exceed 32 inches for car clearance, but this distance is seldom obtained.

3. Complication occurs where complete control of electric power for trains is absolutely necessary, namely in freight yards and switching points, at turnouts and crossovers, and at ladder tracks or puzzle switches. No gaps can be jumped in freight service. There is enough of complication, risk, danger, and hurry, without that which is added by a 600-volt third-rail at the side of the track. The overhead third-rail construction required at crossing switches, 22 feet out of the way, is so heavy that the supporting bridges increase the complication and danger because the heavy structures near the rails obstruct the view of the track and signals.

4. Derail switches and dwarf switches are harder to install and to operate; and frequently they cannot be seen, on account of the obstruction of the view by the third rail.

5. Leakage thru broken insulation increases the danger, particularly at night. Many insulators are broken by accidental falling of metal across the third rail. Block signal systems may thus be made temporarily unserviceable.

6. The use of 1200 to 1500 volts on third rails increases the danger from fire, danger during snow-plow operation, deaths by shock, leakage to signal circuits, burning of insulators, etc.

7. Cost of third-rail construction in freight yards is three times as great as the cost of overhead high-voltage contact lines.

**Return conductors** are the track rails and supplementary copper feeders which form the return circuit. The rail resistance loss is often negligible in high-voltage electric systems wherein a large part of the current "returns" to the power plant thru the earth. With low-voltage systems the loss usually exceeds 3 per cent. and in the latter case the rail joints must be carefully connected by expensive rail bonds, except in three-wire neutral-track systems.

Automatic block-signal circuits require the use of one of the rails of each single track.

**Fourth rails** are used by London Electric Railways Company, to reduce the loss in voltage drop along the earthbed rail return, which, by Board of Trade Rules, to prevent electrolysis, must not exceed 7 volts and must be an insulated return. Fortenbaugh in a paper to A. I. E. E., Jan., 1908, states the objections to fourth rails.

A treatise on return conductors would include the following subjects: Relative resistance of steel and copper; rail bonds, their section, length, location, life, and maintenance; impedance and resistance; losses in energy; damage by electrolysis, etc. See references which follow.

## COST OF CONSTRUCTION.

**Insulators** for high-voltage transmission lines are made in several types as noted below. The factor of safety desired controls the cost. Factory prices average about as set forth in the following:

| | |
|---|---|
| 12,000- to 22,000-volt, 3-shell, pin-type | $ .40 to $ .50 |
| 33,000- to 44,000-volt, 3-shell, pin-type | .50 to .75 |
| 44,000- to 55,000-volt, 3-shell, pin-type | .75 to 1.00 |
| 60,000- to 66,000-volt, 4-shell, pin-type | 1.00 to 1.10 |
| 20,000- to 25,000-volt, 1-disk, susp.-type | .75 to 1.25 |
| 60,000- to 75,000-volt, 3-disk, susp.-type | 2.25 to 3.00 |
| 20,000- to 25,000-volt, 1-disk, cone-type | 1.00 to 1.50 |
| Each malleable insulator pin, with separate ferrule, extra | .35 |
| Each malleable suspender or clamp for disk, link, or cone, extra | .25 |

**Cost of poles** cannot be stated for a general case. Length, kind of material, freight, and foundations are the variables.

**Towers** for steel transmission lines are generally made of angles and channels of standard section. The cost of fabricated steel, f.o.b cars at factory, is about 3 cents per pound, and 3 1/2 cents galvanized.

**Bridges** of fabricated structural steel, used for supporting 2- to 6-track catenary construction, cost, f.o.b. cars at factory, about 3 cents per pound.

## COST OF THREE-PHASE HIGH-TENSION TRANSMISSION LINES.

Comparative Data per Mile of Transmission.

| Type of construction. | Wooden poles. | | Steel towers. |
|---|---|---|---|
| Voltage. | 13,000 | 60,000 | 60,000 |
| Support, 50 poles or 12 towers | $350 | $650 | $1800 |
| Cross arm, 50 on poles; part of towers | 100 | 380 | ..... |
| Telephone line material | 50 | 50 | 75 |
| Ground wire material | 35 | 40 | 100 |
| Insulator pins | 35 | 130 | 0 |
| Insulators | 30 | 550 | 155 |
| Three No. O wires, erected | 1000 | 1000 | 1000 |
| Installation of wires, guys, and insulators | 200 | 200 | 270 |
| Total | $2000 | $3000 | $3400 |

Towers for a 6-wire transmission line cost about $2400.

Estimate omits cost of right-of-way, 15 per cent. for contractor's profit, 5 per cent. for engineering and 5 per cent. for contingencies. Change for actual size of wire to be used.

## COST OF CATENARY CONTACT LINE.

| Name of railway. | Voltage used one-phase. | Brackets, bridges or poles. | No. of tracks. | Spans in feet. | Cost per single-track mile. |
|---|---|---|---|---|---|
| Heaviest interurban | 11,000 | Bracket | 1–2 | 150 | $2150 |
| Light interurban | 11,000 | Bracket | 1 | 150 | 1800 |
| | | Span | 1 | 150 | 2300 |
| Steam R. R. electrification | 11,000 | Bridge | 2 | 300 | 3000 to 6000 |
| Steam R. R. electrification | 11,000 | Bridge | 4 | 300 | 7000 to 10000 |
| New York, New Haven & Hartford. Main line. | 11,000 | Bridge | 4 | 300 | 17000 with foundations |
| New York, New Haven & Hartford. Harlem Yards. | 11,000 | Tower and cable | Yards. 6 to 9 | 250 | 1800 |
| Hamburg-Altoona | 6,000 | Bridge | 2 | 157 | 5000 |
| Seebach-Wettingen | 12,000 | Wooden pole | 1 | 164 | 4100 |
| Rotterdam-Hague-Scheveningen. | 10,000 | Latticed pole and light bridge | 2 | 157 | 5450 |
| Three-phase | 6,000 | Bracket | 1 | 150 | 5600 |
| Two 4/0 wires. No catenary. | 6,000 | Span | ..... | ..... | 8000 |

## COST OF CATENARY CONTACT LINES.

Estimate per mile of Double Track. Comparative.

| | |
|---|---|
| Poles, span cable hangers, without catenary | $1100 |
| Poles, brackets, messenger suspenders, catenary | 1300 |
| Bridges, messenger, suspenders, catenary | 1700 |
| Add for insulators and miscellaneous | 250 |
| Add for two 4/0 copper trolleys | 2000 |
| Add for labor and tools | 1200 to 1450 |
| Total cost per double-track mile | $4800 to $5400 |

## COST OF THIRD-RAIL LINES PER MILE.

| Name of railway. | Pounds per yard. | Under- or over-running. | Cost of complete work. Material. | Labor. | Total. |
|---|---|---|---|---|---|
| Michigan United Ry | 60 | Over-running | | | $3000 |
| Estimate by Armstrong | 70 | | $3575 | 920 | 4475 |
| California Traction, 1200-volt. | 40 | Under-running | 2748 | 552 | 3300 |
| Boston & Eastern | 90 | Protected, u.-r. | | | 4700 |
| Heavy interurban | 70 | Protected, o.-r. | | | 4000 |
| Railroad electrification | 100 | Protected, o.-r. | | | 6000 |

Steel rails, 70 pounds at $35 per 2240-pound ton cost $1950 per mile.

Michigan United Railway Company reports that its third-rail installation cost about the same as a 4/0 trolley with one 500,000 cm. feeder on 35-foot poles; and that the third rail has 50 per cent. greater capacity. A 60-pound, low-carbon Carnegie rail costing $35 per ton, had a capacity of 1,080,000 cm. and a relative conductivity of 6.83. It was installed on vitrified clay block insulators for a total cost of $3000 per mile.

Cost of maintenance of 142 miles of third-rail contact line on the West Jersey and Seashore Railroad for 1910 was $10,864 or $77 per year per mile.

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*This page is reserved for additional references and notes on transmission and contact lines.*

## CHAPTER XIII.

# STEAM, GAS, AND WATER POWER PLANTS FOR RAILWAY TRAIN SERVICE.

### Outline.

**Distinguishing Features:**

Capacity, economy of operation, relatively constant load, relatively small amount of equipment.

**Load Factor of Railway Loads:**

Train movements per day, hours of service per day, acceleration rates used, kind of service, length of division, equalization of loads, variety of service, electric system used.

**Steam Power Plants:**

Location, water supply, coal supply, coal handling, furnace, grate surface, heating surface, water-tube boilers, steam turbines, condensers, heat insulation, supervision, number of plants, reliability of service, cost of all equipment, cost of power per kw-hr., installations for railways.

**Gas Power Plants:**

Reasons for limited use, conditions which favor development, present status, cost of equipment, cost of operation, installations for railways.

**Water Power Plants:**

Water supply and load, water power available, reliability, cost of equipment, cost of power per kw-hr., installations for railways.

**Technical Descriptions of Installations:**

New York, New Haven & Hartford; New York Central; Interboro Rapid Transit; Hudson & Manhattan; Long Island-Pennsylvania; West Jersey & Seashore; Commonwealth Edison; Twin City Rapid Transit; Milwaukee Northern; Great Northern Railway, Cascade Tunnel; London Electric Railways.

**Literature.**

## CHAPTER XIII.

# POWER PLANTS FOR RAILWAY TRAIN SERVICE.

### DISTINGUISHING FEATURES.

Power plants which supply energy for electric railway train service generally have at least four distinguishing features or characteristics:

**The capacity** of one central power plant is used to provide energy for propelling many electric trains or is substituted for that of many steam locomotives. The capacity of the electric power plant is relatively unlimited so far as any train is concerned, and the whole power plant stands behind the individual electric train. The maximum output from the central plant is large, compared with the capacity of a steam locomotive, a power plant on wheels. Electrical machinery has a limited capacity, but generally this is fixed by the safe heating of the mica or other insulation around copper conductors, and heavy overloads can be carried for long periods with safety. The maximum output of a steam locomotive is limited by its boiler and cylinders.

**Economy in operation** is guaranteed because the number of prime movers at the power plant which are in service at any one time can be so varied that each will operate within its most economical range of load. Operation on a large scale reduces the items of labor, of maintenance, and of fixed charges per unit output. These are the essentials for economy of power production.

**Relatively constant loads** exist at the central plant while the power service furnished by the single locomotive or car varies continually over a wide range. "The load factor or average load of trunk-line railways will be from 60 to 80 per cent. of the maximum load." *Stillwell.* The larger the electric zone and the greater the number of the trains in service, the more constant the plant load becomes, because the loads of the different trains are distributed, giving a low value for the maximum, and further, the peaks for acceleration do not occur simultaneously, and all of the trains are not moving all of the time.

**Relatively small amounts of equipment** are necessary, for the above reasons. The power plant equipment has from 30 to 50 per cent. of the total or maximum capacity of the steam or electric motors used to haul the trains. The relation of the rated capacity of the electric power plant to the capacity of the motors in the trains is shown in the table which follows.

RELATIVE EQUIPMENT OF POWER PLANT AND RAILWAY MOTORS.
Data are for 1910. 1 kw. = 1.34 h.p.

| Name of railway company. | Capacity of power plant. 24-hr. h. p. | Capacity locomotives. 1-hr. h. p. | Capacity motor-cars. 1-hr. h. p. | Capacity motors, total h. p. | Ratio of h.p., power plant to railway motors. |
|---|---|---|---|---|---|
| Boston and Maine | 5,333 | 6,300 | 0 | 6,300 | .85 |
| New York, New Haven & Hartford: | | | | | |
| New York Division | 21,500 | 42,480 | 3,900 | 46,380 | .46 |
| New York Central: | | | | | |
| Hudson and Harlem Divisions. | 53,333 | 103,400 | 60,000 | 163,400 | .33 |
| Hudson & Manhattan | 24,000 | 0 | 64,400 | 64,400 | .37 |
| Pennsylvania R. R.: | | | | | |
| Pennsylvania Tunnel and Terminal. | 44,000 | 82,500 | 96,750 | 233,650 | .19 |
| Long Island R. R. | | 0 | 54,400 | | |
| West Jersey & Seashore | 10,666 | 0 | 44,640 | 44,640 | .24 |
| Baltimore & Annapolis | 2,400 | 0 | 4,800 | 4,800 | .50 |
| Erie R. R., Rochester Division | 3,000 | 0 | 2,400 | 2,400 | 1.25 |
| Baltimore & Ohio | 4,000 | 11,600 | 0 | 11,600 | .35 |
| Grand Trunk, Sarnia Tunnel | 3,333 | 4,320 | 0 | 4,320 | .81 |
| Michigan Central, Detroit Tunnel | 2,666 | 6,600 | 0 | 6,600 | .41 |
| Twin City Rapid Transit, | | | | | |
| Minneapolis-St. Paul | 67,000 | 400 | 174,000 | 174,400 | .39 |
| Colorado & Southern: | | | | | |
| Denver & Interurban Division | 2,680 | 0 | 5,000 | 5,000 | .54 |
| Valtellina Ry., Italy | 7,400 | 7,200 | 2,800 | 10,000 | .74 |

A study of this statistical table should include the following:

Reserve equipment in power plant, and in locomotives and motor cars; method of rating railway motors; relation of kw. to kv-a. output of power plant; use of storage batteries to equalize the loads; use of steam power as a reserve for water power; rapidly changing and temporary conditions; large initial power plant investment for considerable increase in the train service; size of installation; number of locomotives in service.

A further study of the reasons for the relative amounts of equipment would include the ratio of average and maximum power plant loads to the capacity of the railway motor and power plant equipment in service. For example, on the New Haven road, in October, 1909, the railway power plant capacity at Cos Cob was 17,100 kw., the peak load was about 11,000 kw., and 1000 kw. were used for lighting, pumping, and other work, leaving a 10,000-kw. load for 20, of 38, electric locomotives which were in service in the zone fed by the Cos Cob power plant; thus the average power plant load for each 1000-h. p. passenger locomotive approximated 500 kilowatts.

### LOAD FACTOR OF RAILWAY LOADS.

The load factor, or the ratio of the average load to the maximum load, as determined daily or monthly by watt-hour meters, is relatively high at an electric railway power plant; and as a result, the equip-

ment required is a minimum for a given amount of energy delivered. (The load factor for a period of 5 minutes differs from the load factor for 1 hour, 1 day, or 1 year; and for accuracy the period of time should be specified. Ordinarily the time limit is for a period of 1 hour, because watt-hour meters at central power plants are read hourly.) The matter of power factor is of importance because it has a direct bearing upon the economy of power service.

The load factor of a power plant depends upon the number of train movements per day; number of hours of service per day; acceleration rates; kind of service furnished; length of the electric division; equalization of the load with other power plants; variety of service or loads; electric system used for electrification, etc.

**The number of trains** is of first importance. There is no advantage to be gained by replacing steam locomotives with electric locomotives when there are only a few train movements per day. In such cases, the interest on the increased cost of the power plant, and the transmission line, cannot be compensated in any measure by the physical advantages of electric traction and the saving to be made in fuel; but with 6 freight trains, 6 passenger trains on thru service, 6 passenger trains in local service, and 8 switchers, the load factor is raised, and physical and financial advantages are gained.

**Total number of hours of service per day** affects the load factor. In 24-hour electric railway train service the load factor easily exceeds 50 per cent., which is about the maximum obtained in 18-hour street railway service. Electric lighting plants have the greater part of their load within a period of 4 hours and the load factor is about 25 per cent.

**Acceleration rates** used in different kinds of service affect the load factor, but only to a small extent. In railway practice the accelerating rate varies universally as the train weight, and the tractive effort required in accelerating heavy trains is not materially different from that of lighter trains, as is shown in the following table.

TRACTIVE EFFORT FOR DIFFERENT RAILWAY SERVICES.

| Kind of train service. | Accelerating rate in m. p. h. p. s. | Tons per train. | Tractive effort acceleration. | Tractive effort at full speed. |
|---|---|---|---|---|
| Rapid transit.......... | 1.25 | 160 | 20,000 | 2,800 |
| Short train.............. | .70 | 250 | 17,500 | 3,500 |
| Local passenger......... | .40 | 400 | 16,000 | 4,400 |
| Thru passenger......... | .25 | 600 | 15,000 | 6,000 |
| Way freight............. | .10 | 1500 | 15,000 | 10,000 |
| Thru freight............ | .05 | 2800 | 14,000 | 16,800 |

Tractive effort (acceleration rate $\times$ 100) $\times$ m. p. h./375 = h. p.

The greater number of trains in rapid transit and suburban service compensate for the higher tractive effort per train during acceleration.

**Kind of service** affects the load factor. For example, the load factor of a passenger terminal of a railroad is low. The passenger service is hard to handle with economy because trains are bunched during the morning and evening, and because the total hours of heavy service are 18, rather than 24, per day. Freight service, however, is well distributed during the night and day. Trains leave early in the morning, between 6 and 7 A. M., and usually arrive at their destination between 4 and 5 P. M., or before the heaviest passenger traffic starts. If a single-track line is used, or if the traffic is heavy, the train dispatchers keep the line uniformly busy, during the 24 hours. With a small change in the schedule, the peak load may sometimes be radically decreased without changing the value of the service rendered.

**Length of the division** affects the load factor. The load factor of the power plant which furnishes service for a short division or for a short terminal is generally low, even with a large number of trains. It might be 30 per cent. on a 10-mile terminal division, while if two adjacent divisions were added, forming a total of 100 miles, and if the freight service were included, the load factor might be 80 per cent. Obviously it is about as easy to handle a 50-mile division as to handle a 5-mile tunnel.

When a large central power plant supplies energy to 40 electric trains on long freight and passenger runs, day and night, the conditions change and the business is handled with economy.

New Haven Railroad Company's power plant at Cos Cob has a poor load factor and bad fluctuations in load. About 20 electric locomotives haul heavy passenger trains on 20 miles of 11,000-volt road. (A short trolley road with 20 cars has an equally poor load factor.) When the electric zone reaches to New Haven, and the freight and switching work is included, the percentage of the fluctuations will decrease; the load will extend over more hours of the day, and it will not be necessary to run a 4000-h. p. turbo-alternator from midnight to morning, practically without load.

Many railroads have now spent $1,000,000 at tunnels for the electrification of about 6 miles of route, using about 6 locomotives, to haul all freight and passenger trains thru a long tunnel and over connecting grades, to gain in capacity and to avoid dangerous operation. The net saving in operating expenses, about $100 per day, cannot pay one-third of the interest and depreciation on the capital invested. When a second million dollars has been spent, for the electrification of an adjacent division and terminal yards, economy will be expected,

because the load factor of the entire plant will be radically increased, and because the investment will be utilized during more of the time.

Grand Trunk Railway has a serviceable, reliable, and expensive power plant at Port Huron. A 1000-ton freight train is accelerated, then there is a short run on the level, followed by coasting and by a run up a 2 per cent. grade. The number of trains in operation at one time, with six 66-ton locomotive units, is not more than two. Economy cannot be expected until 10 to 20 passenger, freight, and switching trains are in service at one time to equalize the boiler and turbine loads. Difficulties and handicaps exist, as with the 6-mile, 6-car street railway, in 1890. The relative results of electric train operation are, however, decidedly better than with steam locomotives; but the mileage of the electric division must be increased for real economy.

**Equalization of the loads** of two or more power plants which feed a 150-mile or a longer division increases the load factor, if the two plants are connected thru feeders or even thru the contact line, because the peak loads or fluctuations of the load on the two power plants will be equalized or divided among the power plants to the East and to the West, even tho they are 100 miles apart. Incidentally this interconnection increases the reliability and also the ability to handle peak-load service under the conditions which arise after a storm has damaged tracks, bridges, equipment, and transmission lines.

Storage batteries may be used to equalize the load. Plans have been developed to pump water to heights during light-load periods and to release it thru Pelton water wheels during the heavy-load periods. Other plans involve a fly wheel connected to a large motor to store up energy and return it on demand to carry a temporary peak load. Elec. World, Feb. 23, 1911, p. 487; Tatum: A. I. E. E., April 12, 1911.

On the Italian State Railway's Mont Cenis three-phase road, between Modana and Turin, water power is furnished thru the following frequency changer outfit. One 2200-kv-a., 50-cycle, 48,500/7000-volt, three-phase transformer; one 2500-h. p., 7000-volt, 50-cycle induction motor; a 44-ton fly-wheel; a 2000-kv-a., 500-r. p. m., 3500-volt, 16 2/3-cycle, three-phase generator; and one three-phase commutator motor for regulating the speed of an asynchronous motor between 400 r. p. m., and 500 r. p. m. The fly wheel stores kinetic energy to such an extent that when the speed drops from 500 r. p. m. to 400 r. p. m., about 1000 h. p. can be given up for 1 minute to care for locomotive load fluctuations. The three-phase commutator motor permits the asynchronous motor, with which it is connected in cascade, to approximate unit load factor.

**Variety of service** or of loads is an advantage. The load factor is increased by handling electric service for lighting, street railways, shops, or city water pumping, coal handling at docks, and hoisting at wharves, bridges, and elevators located along the line. It is frequently observed, in electric railway train diagrams, that there is a *sag* in the total load

about 6 P. M. daily; for the freight trains are in, the switchers are resting, and for an hour or so some of the heavy trains are not started. This fact can be used to advantage because the peak loads of street and suburban railways, and the electric lighting loads occur at this time. The minimum boiler capacity is thus required for the combined peaks and, with the excellent load factor, economical service can be provided.

**The electric system** used affects the load factor. For example, when using the three-phase or single-phase system for regeneration of energy on mountainous grades, a train going down the grade hauls a train up the grade, and thus decreases the peak loads. When a sudden load comes on the power plant, a sluggishly designed governor on the prime mover causes it to slow down, and the three-phase locomotive assists the power plant temporarily by a kind of fly-wheel action. The instant the generators are slowed down by any sudden load, all the motors on the line are operated temporarily by the inertia of their railway trains, and the power taken from the line is temporarily decreased.

*Waterman* states that on the three-phase Valtellina road in Italy, with 5 or 6 light trains running simultaneously, the ratio of peak to average load is 1.75, or that the load factor is 57 per cent. Studies of the Valtellina power plant economies indicate that on account of the improved load factor the three-phase system can be operated with a smaller power plant capacity. In real railroading, this gain by fly-wheel action would be much more than overbalanced by the great overloads that occur when the speed of three-phase motors is maintained, with the drawbar pull, on the up-grade work in rough rolling country.

Direct-current and single-phase systems produce the highest power-plant load factor. The product of speed and torque is such that the power is nearly constant. Acceleration, and up-grade runs, which require high torque are compensated by lower speeds. The speed of the series motor and the power developed depend on the voltage applied to the motor.

Three-phase systems affect the load factor adversely. In the polyphase motor the speed remains constant with increase of torque required on the up-grade; the power rises, and the relation of average to maximum load becomes lower, which is bad for the economical production of power. The load varies over wide limits. On a 2.2 per cent. grade it is 5 times as high as on the level. In accelerating, the power required is 20 per cent. greater than in running at full load, even when slip-ring motors are used, and the rate of acceleration is low. Great Northern Railway one-speed locomotives take full rated power from the instant of starting.

The load factor of a power plant affects the economy in operation, fuel, labor, maintenance, and investment. This point is obvious. The data which follow under Cost of Power show the remarkable variation in the cost of power with a change in the load factor.

## STEAM POWER PLANTS.

**Location** of steam power plants is governed largely by the water and coal supply. The power plant may be placed at almost any supply point on the railroad division, providing it is known that ultimately the adjacent divisions will be electrified. The center of gravity of the load is generally not the best point for the power plant since the length and cost of the transmission lines and the losses in lines do not govern plant economy, or the total cost of operation.

**Water supply** which is convenient and suited to maximum economy of boiler operation is obtained. Sufficient water for condensing the steam is usually essential.

**Coal supply** is placed where there is ample storage. It is not rehauled and redistributed to locomotive units. The coal is of a cheap grade, costing much less than the lump, or mine-run coal burned on a moving steam locomotive. In the production and sale of coal, parts called screenings, slack, and culm are readily burned by using mechanical stokers, but they cannot be burned on locomotives; yet these screenings can be obtained for from 20 to 50 per cent. of the cost of lump coal, and they contain 80 to 90 per cent. of the maximum heat units. Expenses are thus reduced, and natural resources are conserved, when they are used.

**Lignite coal** can be utilized where it is abundant and cheap. It slacks quickly and loses its heat units when broken or exposed during transportation. Lignite cannot be burned in locomotive furnaces, unless it is treated or briquetted. In the Dakotas, Montana, Wyoming, and Washington, the Northern Pacific, Great Northern, Chicago, Milwaukee & Puget Sound, and "Soo" railroads could use to advantage the immense deposits of lignite for electric traction, and the power plants could be located at mines. Electrification has repeatedly received consideration by these Northwestern roads, which now use Pittsburg coal. Incidentally, the cost of boiler-tube repairs and of washing out of boilers in which alkali, foaming, and bad waters are used are now a heavy maintenance expense.

The cost of good coal is ordinarily 50 to 75 cents per long ton at the mine, and the cost of transportation, rehandling at docks, coal depots, etc., forms the larger part of the cost. Power plants can be located to advantage at coal mines or at docks, to save the cost of handling and of freight haulage. It is obviously cheaper to transmit the energy from coal by wires than to transport the coal itself on freight cars.

Electric railway plants are now being built at coal mines. Eifel Bahn, a double-track, 112-mile road which is to run from Cologne to Treves, will obtain power from lignite coal fields. Many European roads now utilize lignite and peat for fuel. The money is kept in the state or country. Northern Colorado Power Company generates power at a lignite coal mine and 6000 kilowatts are transmitted 66 miles to several railways, 2000 kilowatts being used by Denver and Interurban railroad. Electric railway power plants are located at mines near Scranton, Pa., Seattle, Wash., Girard, Kansas, etc, and opportunities for similar installations are abundant in Eastern Pennsylvania and in both Northern and Western Illinois.

**Coal- and ash-handling devices** are used in steam power plants, to eliminate the labor required to handle, store, and crush the coal, and to

remove ashes. Money spent for such equipment pays well. Expert firemen are obtained to supervise the operation of boilers. The cost of handling coal from the car to the bunkers is about 8 cents per ton.

**Furnaces** of modern steam power plants are of the stoker type. The coal is broken up and is fed to the stoker by machinery, and the ashes are cleaned out, regularly and automatically, without opening the furnace doors and chilling the furnace by cold air. The proportions of air and coal are well regulated, and the draft is varied automatically to assist in producing maximum economy. Combustion is perfected. The combustion chamber is high and it is not restricted in volume. The coal is first volatilized, the carbon is combined at the right time with the hydrogen of the air; the hydro-carbon then unites with oxygen, and the carbon which is floating in the hydrogen flame does not come in contact with the relatively cold tubes or plates until combustion is completed. As a result, smoke is avoided. The furnace is surrounded by fire brick and tile. If the tubes and other heating surface are within 5 feet of the grates, they are covered with tile. After the coal ignites, the gases travel a distance of 6 to 8 feet under an incandescent tile arch. Baffles are placed in the combustion chamber to hasten the mixture of the air and gases as they leave the fire at times of overload, and the stratification of the gases, which naturally prevails, is prevented. This furnace design increases the economy and capacity of the boiler.

**Grate surface** is such that the number of square feet per square foot of heating surface is several times larger in the stationary boiler than in the locomotive boiler. A great output for sudden overloads is thus possible and cheap grades of coal can be burned efficiently.

**Heating surfaces** of boilers are of ample area, and the gases leave the boilers at low temperatures. Each boiler unit has from 5000 to 9000 square feet of heating surface and this reduces the cost of the unit. Radiation and maintenance are a minimum.

**Water-tube boilers** are used, because it is easy to keep the inside and outside of the tubes clean, and thus to *maintain* the high efficiency. Water-tube boilers are rated at 10 square feet of heating surface per h. p., but they are capable of withstanding about 100 per cent. overload continually, and are so operated in the largest central stations.

High steam pressures increase the thermal efficiency of the turbines, without the excessive repairs and radiation of locomotive boilers.

Superheat, with its thermal advantage for the prime mover, becomes practical in central station boilers and prime movers.

Feed-water heaters and waste-gas economizers increase the efficiency of the boiler plant from 12 to 20 per cent.

**Steam turbines** are used in the power plant because of their economy of steam. They have the following important features:

Poppet valves with an exact, quick-acting mechanism and minimum wearing surface, admit the steam thru large openings.

Cylinder condensation is a minimum. The walls are not heated and cooled as in reciprocating engines.

Utilization of the energy available in the steam is excellent because of the wide limits which are practical for expansion. The total energy in steam at 150 pounds gage pressure is about 1195 B. t. u., of which about 321 B. t. u. can be utilized between this pressure and a 28-inch vacuum. A gain in energy of 33 per cent. is obtained when the vacuum is increased from 24 to 29 inches.

Steam turbines in sizes up to 20,000 kw., direct-connected to electric generators, have superseded engines.

**Condensers** are used, and they increase the capacity and the economy of the prime mover fully 25 per cent. The auxiliary equipment to produce a 28-inch vacuum requires 3 to 4 per cent. of the total output of the prime mover. A simple jet or barometric condenser is preferable, but a surface condenser is more often advantageous. When the water contains salt, sewage, alkali, or minerals, condensed steam can be used over and over again in the boiler to prevent the foaming which accompanies alkali waters, the pitting and corroding of steel, or the deposit of hard, porcelain scale in the boiler tubes.

**Heat insulators** surround the furnaces, boilers, piping, and prime movers. Radiation losses and cylinder condensation, which are large in steam locomotives, are relatively small. The central plant is protected from the elements and from the cold winds.

**Operators** supervise the production of the power, and do not work by brute force. The firemen can become expert, and their entire time can be given to the economical production of steam. The boiler room becomes the important place for the scientific production of power. Coal and flue-gas analyses, checks on the temperatures, and continual tests are practical, and of economic value in the large central station. Meters assist in checking results, and comparative data are readily and continually obtained.

**Number of power plants** used depends largely upon the reliability of service which is desired. Two interconnected, well-separated plants are necessary for important service. Economical limits of power transmission are not reached by radial feeders 100 miles long, or the length of a railroad division. Prudence may dictate that two power plants per 150 miles of route are necessary; yet many electric railways have only one power plant for 300 miles of single track.

Railroads must, of course, combine their interests, and use one power plant to supply many railroads and many routes, to avoid duplication in power equipment, and also to obtain high load factors and economy in

power production. Union railroad terminals illustrate the present joint use of heat, power, and light from one power plant. Many electric railroads now purchase electric power from unaffiliated power corporations.

**Reliability of service** can be guaranteed in railway power plants. A number of boilers, turbines, and generator units are required for economical power production, and trouble at one unit is automatically blocked off and isolated, so that it cannot affect continuous service from the plant. Two or more power plants are often tied together by duplicate transmission lines, so that in case of trouble assistance can be obtained. The contact line, however, cannot be in duplicate, and it must therefore be of the simplest character.

**Cost of equipment** varies with the size and to some extent with the type of equipment, and always with the degree of reliability which is desired of the complete installation.

Steam turbines and electric generators are designed to have maximum efficiency at about rated load. They can carry an overload of 50 per cent. for 2 hours, following the full rated load, with safety, and can carry 25 per cent. overload continually with a small reduction in efficiency. Electrical equipment is purchased and is accepted only after a test with a 24-hour full-load, during which the temperature rise is less than 50° C. as measured by a thermometer. Insulation of mica, tape, and compounds are not deteriorated by a temperature of 75° C.

The data available show that a complete modern steam railway plant can generally be constructed for the following:

COST OF STEAM POWER PLANTS AND EQUIPMENT.

| | |
|---|---|
| 100,000-kilowatt plants cost, complete | $ 60 per kw. |
| 40,000-kilowatt plants cost, complete | 70 per kw. |
| 20,000-kilowatt plants cost, complete | 80 per kw. |
| 10,000-kilowatt plants cost, complete | 90 per kw. |
| 5,000-kilowatt plants cost, complete | 100 per kw. |
| 2,500-kilowatt plants cost, complete | 140 per kw. |
| Station buildings and land add from | $10 to 20 per kw. |
| A large-sized boiler, complete, costs | $14 to 20 per h. p. |
| One boiler h. p. is used for 2 kw., when 15 lb. of steam are used per kw.-hr. | |
| Chimneys cost from $4 to $6 per h. p., depending upon permanence, not on size. | |
| 5000-kilowatt turbo-generators cost, complete | $30 per kw. |
| 8000-kilowatt turbo-generators cost, complete | 25 per kw. |
| 14,000-kilowatt turbo-generators cost, complete | 20 per kw. |
| Large rotary-converter substations cost, complete | 40 per kw. |
| Large motor-generator substations cost, complete | 44 per kw. |
| Large transformer substations cost, complete | 8 to 10 per kw. |

The relative cost of steam power plants, from an average of the best comparable data obtainable, is: Water power plants, 100; water and

steam plants, 125; steam turbine plants, 155; gas producer and engine plants, 180.

**The cost of power** will depend largely upon:

a. Load factor or uniformity of load. (See load factor, page 468.)

b. Economy of steam per h. p. hr. Steam turbines in larger sizes consume 10 pounds of steam per i. h. p. hr., or 15 pounds per kw-hr.; compound condensing Corliss engines show at best 12 pounds of steam per i. h. p. hr.; modern Mallet compound steam locomotives use 24 pounds per i. h. p. hr. and the ordinary simple steam locomotive in good condition averages fully 30 pounds per i. h. p. hr. The relative steam consumption in the four cases is 10, 12, 24, 30.

Steam in turbines expands 28 to 35 times; in Corliss condensing engines 20 to 25 times, and in simple and compound steam locomotives 3 to 5 times. The ratios are 7: 5: 1.

c. Cost of coal per ton. The cheapest grades of coal are used at large electric power plants.

d. The magnitude of the plant. Many economies are incidental in operation on a large scale.

e. Interest on the cost of the plant. This forms a large item in the cost of service, and therefore it is important to reduce the amount and cost of the equipment used, to have it reliable, and to work it hard. Since electric railway service is generally increasing, the design of the plant should be such that equipment can be added as needed, and with an increase in the economy of fuel and labor.

The cost of steam-electric power varies with the load factor, as is shown by the following example and table. Basis: Steam power plant capacity, 10,000; cost per kilowatt installed complete, $100; coal containing 12,000 B. t. u. per pound of combustible, $2 per 2000 pounds; fixed charges for interest, depreciation, and taxes, 12 per cent. per annum.

COST OF STEAM-ELECTRIC POWER PER KW-HR. ESTIMATED FOR VARYING LOAD FACTORS.

| Load Factor. | Ratio of evap. | Steam per kw-hr. | Cost of coal. | Cost of labor. | Other items. | Operating charges. | Fixed charges. | Total cost. |
|---|---|---|---|---|---|---|---|---|
| 10 | 8.0 | 24 lb. | .60¢ | .13¢ | .12¢ | .85¢ | 1.40¢ | 2.25¢ |
| 25 | 8.5 | 19 | .45 | .07 | .08 | .60 | .56 | 1.16 |
| 50 | 9.0 | 18 | .40 | .05 | .07 | .52 | .28 | .80 |
| 75 | 9.0 | 17 | .38 | .04 | .07 | .49 | .21 | .70 |
| 100 | 9.0 | 16 | .36 | .03 | .07 | .46 | .14 | .60 |

See companion table on Cost of Hydro-electric Power, page 484.

COST OF STEAM-ELECTRIC POWER PER KW-HR. AT LEADING RAILWAY PLANTS.

| Name of railway. | Cost of coal per 2000 lb. | B.t.u. per kw-hr. | Operating cost at Power house. | Operating cost at Contact line. | Total cost at Power house. | Total cost at Contact line. | Load factor. | Year ending June. |
|---|---|---|---|---|---|---|---|---|
| Boston Elevated | $3.20 | | .81¢ | ¢ | ¢ | ¢ | .37 | 1910 |
| Boston & Worcester | 4.58 | | .76 | | | | | 1906 |
| New Haven: | | | | | | | | |
| Consolidated, New Haven. | 3.75 | | .60 | | | | | |
| Cos Cob. | | | | | | | | |
| New York Central | | | .58 | 1.09 | 1.02 | 2.60 | .48 | 1908 |
| Brooklyn Rapid Transit | | | .56 | | | | | |
| Interboro, Rapid Transit | 3.15 | | .60 | | 1.00 | | | 1909 |
| New York Edison | 2.80 | | | | | | | 1909 |
| Long Island R. R | 2.51 | | .70 | 1.46 | | | | 1908 |
| West Jersey & Seashore | 2.18 | | .59 | 1.15 | | | .35 | 1908 |
| | 2.23 | | .54 | .65 | | | | 1910 |
| Hudson & Manhattan | | | | | | | | |
| Philadelphia R. T | | | .55 | | | | | 1908 |
| Harrisburg, Pa | | | .65 | | | | | |
| Pittsburg Rys | 1.04 | | .60 | | | | | 1909 |
| International, Buffalo | 2.25 | | .62 | | | | | |
| Ohio Electric Ry | | | .73 | | | | | |
| Indiana Union Traction | | | .53 | .91 | | | | |
| Kokomo, Marion & West | | | .69 | .91 | | | | |
| United Rys., Detroit | 1.65 | | .51 | | | | | |
| Indianapolis & Cincinnati | | | .65 | .68 | | | | 1907 |
| Chicago City Ry | 1.80 | | .64 | | | | | 1909 |
| Commonwealth, Chicago | 1.60 | 28,000 | | | | | .41 | 1910 |
| Chicago & Milwaukee | 1.78 | 53,306 | .62 | | | | | 1909 |
| Milwaukee Electric Ry | 2.74 | 48,625 | .59 | | | | | 1910 |
| Twin City Rapid Transit | 2.26 | 44,000 | .66 | | .88 | | .55 | 1910 |
| Paris-Orleans | | | .80 | 1.34 | | | | 1905 |
| Paris-Versailles | 1.24 | | | 2.40 | | | | 1905 |

Manhattan Elevated Railroad records show: Pounds of coal per kw-hr. at the power house 2.6, or 3.2 pounds of coal per drawbar h. p. at the train. Its former compound steam locomotives averaged 7 pounds of coal per drawbar horse power.

Cost of power is seldom controlled by the size of the plant, or by the cost of coal; but depends largely upon the average daily load factor, as noted in the table, page 477.

Load factor is defined as the ratio of the average power output for the year to the maximum output for one hour, both being measured by watt-hour meters.

COST OF POWER AND OUTPUT OF ELECTRIC RAILROAD PLANTS.

| Name of railroad. | Operating cost of power plant. | Total kw-hr. produced. | Cost per kw-hr. cents. | Year ending June. |
|---|---|---|---|---|
| New York, New Haven & Hartford | $167,098 | .......... | .......... | 1908 |
| | 412,715 | .......... | .......... | 1909 |
| New York Central & Hudson River | 126,495 | 21,800,000 | .580 | 1909 |
| Pennsylvania R. R.: | 450,059 | .......... | .......... | 1909 |
| Long Island | 198,610 | 28,500,000 | .697 | 1908 |
| West Jersey & Seashore | 149,754 | 25,300,000 | .592 | 1908 |
| | 153,450 | 28,312,500 | .542 | 1910 |
| Hudson & Manhattan | 159,929 | .......... | .......... | 1910 |
| Interboro Rapid Transit | 2,172,810 | 402,085,000 | .543 | 1908 |
| Albany Southern | .......... | 7,982,000 | .874 | 1909 |
| Erie R. R., Rochester Division | 16,154 | .......... | .......... | 1909 |
| Baltimore & Ohio | 71,462 | .......... | .......... | 1909 |
| Twin City Rapid Transit | 724,500 | 116,868,000 | .620 | 1910 |
| Colorado & Southern | 14,000 | .......... | .......... | 1909 |

STEAM-ELECTRIC POWER PLANT INSTALLATIONS FOR ELECTRIC RAILWAY TRAINS.

| Name of railway. | Kilowatts installed. | Motor cars. | Loco-motives. | Mile-age. |
|---|---|---|---|---|
| Boston Elevated Ry.: | | | | |
| Elevated Division | 60,000 | 225 | 2 | 26 |
| Massachusetts Electric | 10,000 | 2,015 | ........ | 933 |
| Rhode Island Providence | 18,500 | 830 | ........ | 318 |
| Shore Line Electric, New Haven | 6,000 | 12 | 0 | 52 |
| Boston & Maine: Hoosac Tunnel | 4,000 | 0 | 5 | 22 |
| New York, New Haven & Hartford: | | | | |
| New York Div., 17,000 kw. in 1910 | 33,100 | 8 | 44 | 100 |
| New York Central & Hudson River: | | | | |
| Harlem Division, Port Morris; Hudson Division, Kings Bridge | 40,000 | 137 | 47 | 150 |
| Manhattan Elevated, 74th Street | 60,000 | 895 | 0 | 119 |
| Interborough Subway, 59th Street | 90,000 | 910 | 0 | 85 |
| Hudson & Manhattan | 18,000 | 200 | 0 | 18 |
| Brooklyn Rapid Transit: El. Div. | .......... | 659 | 15 | 107 |
| Pennsylvania R. R.: | | | | |
| Pennsylvania Tunnel and Terminal | 32,500 | 361 | 33 | 95 |
| Long Island R. R. | | | 2 | 164 |
| West Jersey & Seashore | 8,000 | 108 | 0 | 154 |
| Lackawanna & Wyoming Valley | 5,000 | 35 | 2 | 50 |
| Baltimore & Ohio | 3,000 | 0 | 12 | 7 |

STEAM-ELECTRIC POWER PLANT INSTALLATIONS FOR ELECTRIC RAILWAY TRAINS.—Continued.

| Name of railway. | Kilowatts installed. | Motor cars. | Locomotives. | Mileage. |
|---|---|---|---|---|
| Baltimore & Annapolis Short Line | 1,800 | 12 | 0 | 35 |
| Fonda, Johnstown & Gloversville | 3,000 | 23 | 1 | 85 |
| Erie R. R., Rochester Division | 2,250 | 6 | 0 | 40 |
| Grand Trunk Ry.: | | | | |
| St. Clair Tunnel & Terminal | 2,500 | 0 | 6 | 12 |
| Michigan Central R. R.: | | | | |
| Detroit River Tunnel | 2,000 | 0 | 6 | 19 |
| Fort Wayne & Wabash Valley | 8,500 | 200 | 0 | 212 |
| Indianapolis & Cincinnati | 3,000 | 25 | 0 | 116 |
| Chicago, Lake Shore & South Bend | 4,500 | 24 | 0 | 117 |
| Commonwealth Edison, Chicago: | 244,000 | 2000 | 0 | 1250 |
| Twin City Rapid Transit | 46,000 | 800 | 2 | 380 |
| Minneapolis & St. Paul. | | | | |
| East St. Louis & Suburban | 5,500 | 170 | 2 | 181 |
| Rock Island Southern | 5,000 | 10 | 1 | 82 |
| Central London | 7,100 | 68 | 40 | 13 |
| London Electric | 44,000 | 383 | 4 | 168 |
| Great Northern & City | 3,440 | 35 | 0 | 7 |
| Great Western, M. & W. L | 6,000 | 40 | 0 | 11 |
| Metropolitan Railway | 20,500 | 130 | 11 | 60 |
| City & South London | 3,850 | 0 | 52 | 16 |
| London, Brighton & S. C. | Purchased. | 46 | 0 | 62 |
| Mersey Ry | 3,750 | 24 | 0 | 10 |
| Lancashire & Yorkshire: | | | | |
| Liverpool-Southport | 10,750 | 80 | 0 | 82 |
| North-Eastern | 9,000 | 62 | 6 | 82 |

## GAS POWER PLANTS.

Gas engines and gas producers are used to a very limited extent for electric railway power for the following reasons:

Cost is high because the intermittent action, and instantly applied high pressures used, increase the strains, size, and weight of the engines. Cost varies from $150 to $180 per kilowatt for a complete gas and electric plant, or 50 per cent. more than the cost of a complete steam turbine plant. Cost of gas engines and producers, without electric generators, is twice that of turbines and boilers. Speeds are slow in the best designs, and this increases the cost of the engine, electric generator, foundations, floor space and the power building.

Operation with electric generators in parallel is difficult without excessive rotating weights, but is easier with 15 than with 25 cycles.

Reliability is questioned in all cases. Two spare prime movers are desirable in gas power plants, while one is usual in steam or hydraulic service. However, gas engines in the Edgar Thomson Works and in the U. S. steel plants run for months without an hour's delay.

Manufacturers and users lack experience with the large units of 3000 to 15,000 kilowatts required for railway plants.

Overload capacity of gas engines are small, compared with overload capacity of steam engines and steam turbines.

Producer and engine manufacturers have not worked together in the past, but complete outfits are now built by one manufacturer.

Conditions and location which favor the development of power from gas producers and engines are those wherein:

1. Low grades of coal and lignites are available in original deposits, or as waste in mining.

2. Cost of power, or fuel, or freight, is relatively high. Transportation facilities to handle low-grade fuel may not be available, in which case plants may be located at mines and power may be transmitted by wires over mountains.

3. Natural gas from coke fields, blast furnaces, etc., is available, and cheap, and wherever expenditures for gas producers are avoided.

Economy of fuel is shown by the records of four 2000-kw. units at the Illinois Steel Company's plant, operating on blast-furnace gas, wherein only 15,000 B. t. u. per kw-hr. at the switchboard are used. A gas producer with 75 per cent. efficiency would raise the unit consumption, with coal, to 20,000 B. t. u.

GAS-ELECTRIC POWER PLANT INSTALLATION.

| Name of railway. | Year placed. | Mileage. | No. of units. | H. p. total. | Kw. total. | Name of engine. | Name of producer. | Kind of fuel. |
|---|---|---|---|---|---|---|---|---|
| Boston Elevated........ | 1906 | 20 | 2 | 1220 | 700 | Crossley . . | Loomis . . . | Bit. coal. |
| Elmira Water, Light & R. R. | 1904 | 27 | 1 | 1400 | 750 | Crossley . . | None..... | Nat. Gas. |
| Warren & Jamestown... | 1905 | 42 | 2 | 940 | 500 | West..... | None ..... | Nat. gas. |
| Western N. Y. & Penn.. | 1906 | 93 | 3 | 1500 | 900 | West..... | None..... | Nat. gas. |
| Philadelphia Rapid Tr.. | 1911 | ...... | 1 | 940 | 500 | West..... | Wood.... | Anth.coal. |
| Charlotte Electric Ry... | 1908 | ...... | 2 | 1620 | 1080 | Snow..... | Loomis... | Bit. coal. |
| Georgia Railway & Elec. | 1907 | 166 | 1 | 3000 | 2000 | Snow..... | None..... | Nat. gas. |
| Milwaukee Northern.... | 1907 | 60 | 3 | 6000 | 3000 | Allis...... | Loomis... | Bit. coal. |
| Union Traction, Kansas. | 1907 | 39 | ...... | 1000 | ....... | .......... | None..... | Nat. gas. |
| Missouri & Kansas...... | 1908 | 20 | 2 | 672 | 400 | Buckeye.. | None..... | Nat. gas. |
| Midland Ry., England... | 1908 | 18 | 3 | 750 | 450 | West..... | Mond .... | Bit. coal. |

### WATER POWER PLANTS.

The general characteristics of power plants which were outlined at the beginning of this chapter, namely capacity, economy, relatively constant load, relatively small amount of equipment and load factor, apply to water power plants.

Utilization of water power is a distinguishing feature of electric traction. Water power is usually cheaper than steam. The energy can be utilized for 18 or more hours of the day, because the load factor of the electric railway is higher than for electric lighting. Electric railway companies can purchase power at a lower rate; or they can afford to pay more for a given water power development, because they need more and are able to use it to a better commercial advantage.

Steam railroads are purchasing many of the best water powers in the country. Their heavy loads, excellent load factor, and the economy to be gained with hydro-electric power justified this action.

**Water supply** varies with the season and rainfall, while the total daily load required for railway trains is relatively constant. Water turbines are most efficient at full load and the overload capacity is small. Uniformity of water supply of and demands for power, may be gained in several ways:

a. Water may be stored. Dam sites at the power plant, and reservoirs at the upper reaches of the river, provide for the efficient use of the water and also of the water power investment. Storage of water is often obtained by flooding pasture land during the winter months only. Storage of water in a 300,000-gallon elevated steel tank is provided by the Great Northern Railway for its Cascade Tunnel electric railway plant to equalize the flow and pressure.

b. Electrical energy may be stored in chemical batteries

c. Mechanical energy may be stored in fly wheels, as is now done in electric hoisting, for use during short peak loads. (See Load Factor.)

d. Power may be regenerated by single-phase or three-phase railway motors on heavy grades, so that a down-grade train will furnish most of the energy, required to haul the up-grade train.

e. Train schedule may be revised so that trains do not bunch during a few hours of the day to form a high peak load.

f. Other plans were referred to in the section on Load Factor.

**Water power is available** in sufficient quantities to provide energy for most of the train service in Ontario, Northern New York, Michigan, Wisconsin, Minnesota, Colorado, Utah, Idaho, Montana, and the Pacific Coast states. This energy will be utilized in the future by electric railroads. In mountainous districts energy can be developed at a low cost and this is particularly fortunate since the cost of steam power is highest in mountain service.

**Reliability** of water power plants is often questioned. Many failures have occurred. Some of the causes are listed:

Concealment of facts, or deliberate lying by promotors; incompetent engineering work by inexperienced men; insufficient detail in plans and specifications; lack of provision for local and head water storage; lack of good and uniform foundations; dams built on sand; lack of sheet piling above, in, below, and running the full length of the dam; lack of solid material at the ends of the dam; poor cement; bad concrete; insufficient steel reinforcing; bad setting of good concrete, with poor management; improperly built, graded approaches to dams; inadequate provision to prevent damage by ice shoving; insufficient spillway; congested discharge area; high ratio of flood to low water discharge, especially in small streams and in mountain streams; lack of flowage data covering many years.

(*Note.*—In the northwestern states the absolute minimum flowage in winter is found to average about 0.1 C. F. S. per square mile of drainage area. The low flowage occurs in February, and averages 0.2 C. F. S. while the average flowage during the winter months and during the dry summer months averages about 0.3 C. F. S. per square mile of drainage area. Stillwell gave data, for other parts of the country, to A. I. E. E., June, 1910.)

**Equipment cost** of water power plants for railways varies widely but depends upon:

Cost of site, reservoir, and flowage lands; head or fall of water; constancy of flowage; amount of power developed; distance from railway or lake transportation; permanency of construction; length of transmission; brokerage, risk, and watered stock.

Quantitatively, the cost of complete hydraulic plants averages from $100 to $200 per kilowatt installed. Relatively, the cost of water power plants, from a fair average of all available data, is 80 per cent. of the cost of steam power plants. Installation cost of hydro-electric plants, including substations, but not distributing lines, varies from $200 to $250 per kilowatt of delivered power. A reserve steam plant alone costs an additional $75 per kilowatt. Wooden flumes with a capacity of 200 second feet may cost $30,000 per mile and have an annual charge for interest, depreciation, and maintenance of 20 to 25 per cent. Tunnels in lieu of flumes may cost $100,000 per mile, but the annual charge is nearer 7 per cent.

**The cost of hydro-electric power** varies with the load factor, as is shown by the following example and table.

Hydro-electric plant capacity, 10,000 kilowatts; cost per kilowatt installed complete $200; fixed charges: interest, 6 per cent.; depreciation, 4; taxes, 2; total, 12 per cent., or $24 per kilowatt per year.

Operating expenses, repairs, renewals, and wages vary from $17,500 per year with uniform load to $13,000 per year with lightest load.

COST OF HYDRO-ELECTRIC POWER.
Estimated for Varying Load Factors.

| Load factor. | Operating charges. | Fixed charges. | Cost per kw-hr. | Cost per e. h. p. year. |
|---|---|---|---|---|
| 10 | .16¢ | 2.74¢ | 2.90¢ | $ 18.95 |
| 25 | .06 | 1.10 | 1.16 | 18.95 |
| 50 | .03 | .55 | .58 | 18.95 |
| 75 | .02 | .37 | .39 | 19.12 |
| 100 | .02 | .28 | .30 | 19.60 |

Cost of steam-electric power per kw-hr. (see table page 477) is usually lower than the cost of hydro-electric power when the load factor is less than 25 per cent.

HYDRO-ELECTRIC POWER PLANTS FOR RAILWAYS.

| Name of railway. | Kilowatts installed. | Motor cars. | Locomotives. | Railway mileage. |
|---|---|---|---|---|
| Albany Southern R. R. | .......... | 45 | 1 | 62 |
| Schenectady Ry. | .......... | 157 | 0 | 133 |
| Ottawa Electric Ry. | .......... | 150 | 0 | 45 |
| West Shore R. R. | 600 | 21 | 0 | 114 |
| Ontario Power Co.: | | | | |
| Erie R. R. | 2,250 | 6 | 0 | 40 |
| Lockport; Rochester; Syracuse | 14,500 | .......... | .......... | .......... |
| Niagara Gorge Ry | 1,000 | 28 | 0 | 32 |
| Niagara Falls Power Co.: | | | | |
| International Ry | 10,500 | 950 | 2 | 374 |
| Tonawanda Ry | 1,000 | .......... | 0 | .......... |
| Electrical Development Co: | | | | |
| Niagara, St. Catharine & Toronto | 750 | 16 | 3 | 50 |
| Toronto Ry. Company | 13,000 | 850 | 2 | 114 |
| Canadian Pacific R. R.: | | | | |
| Hull-Aylmer Division | 2,000 | 30 | 2 | 26 |
| Montreal Street Railway | 9,600 | 1000 | 2 | 224 |
| Grand Rapids, Michigan, Rys | 11,000 | .......... | .......... | .......... |
| Indiana & Michigan Electric | 8,000 | .......... | .......... | 150 |
| Illinois Traction (Marseilles) | 2,700 | .......... | .......... | 600 |
| Milwaukee Electric | 6,000 | 398 | 0 | 137 |
| Wisconsin Traction Company | 3,000 | .......... | .......... | .......... |
| T. C. R. T., Minneapolis and St. Paul | 16,000 | 800 | 2 | 380 |
| Duluth-Superior Traction | 1,500 | 119 | 0 | 76 |
| Winnipeg General Power | 4,000 | .......... | .......... | 40 |
| Denver & Interurban R. R | 2,000 | 16 | .......... | 54 |
| Montana Power Transmission | 6,000 | 80 | 0 | 50 |

HYDRO-ELECTRIC POWER PLANTS FOR RAILWAYS.—Continued.

| Name of railway. | Kilowatts installed. | Motor cars. | Locomotives. | Railway mileage. |
|---|---|---|---|---|
| Spokane & Inland Empire | 40,000 | 582 | 14 | 287 |
| Washington Water Power | 21,000 | 130 | 0 | 98 |
| Seattle Electric | 15,000 | 289 | 1 | 170 |
| Puget Sound Electric | | 100 | 10 | 200 |
| Portland Ry., Light and Power | 15,000 | 309 | 7 | 472 |
| Oregon Electric | 2,250 | 24 | 3 | 80 |
| Great Northern | 7,500 | 0 | 4 | 6 |
| United Rys., San Francisco | 26,800 | 425 | | |
| Los Angeles-Pacific | 7,500 | 523 | | 260 |
| Pacific Electric | | 675 | 20 | 700 |
| French Southern | 38,000 | 30 | 7 | 75 |
| Valtellina Ry., Italy | 4,150 | 10 | 6 | 70 |

## TECHNICAL DESCRIPTIONS OF INSTALLATIONS.

### NEW YORK, NEW HAVEN & HARTFORD RAILROAD.

Power plant is installed at Cos Cob, on the main line of the New York division, at an outlet of a river, and on a navigable bay. The location is 30 miles east of New York. In 1910 the plant contained:

Twelve boilers, 525-h.p. each, with 125° superheat, 200 pounds pressure; with Roney stokers, Green economizers, and induced draft; four Parsons-Westinghouse steam turbines; three 3700-kw., 11,000-volt, 25-cycle alternators; and one 6000-kw., 11,000-volt, 25-cycle alternator.

The alternators are three-phase star-connected. Two legs are used, the remaining leg being idle. Transformers and substations are not used between the generators and locomotives, i. e., the station feeds a 11,000-volt contact line directly.

The 1910 power service included the supply of electrical energy to about 20 of 42 locomotives and 4 of 6 motor cars for all electric passenger trains on the 4-track, 22-mile road between Woodlawn, N. Y., and Stamford, Connecticut, and 1000 kilowatts for street railways, shops, pumping, and signals. Energy is purchased from the New York Central for the service between Grand Central Station and Woodlawn, 12 miles.

In the 1910 power service three alternators, with a single-phase rating of 3700 kv-a. at 80 per cent p. f., or 5500 kv-a. three-phase, carried about 1000 amperes at 11,200 to 13,500 volts. The power factor was .75 maximum,. 65 average, and less for minimum loads. Three alternators were used on the peak loads, during which 1700 amperes existed for 30 seconds followed by 400 amperes. High peaks occurred on

Saturdays. The peak load was 12,000 kilowatts yet the minimum load at night averaged 500 kilowatts. The peaks varied from 20 to 30 per cent. above and below the average load, during daylight hours.

Every passenger locomotive is in service during the evening load.

Economy of the station is low because the line is so short that there is no railway load from midnight to morning, during which time a 3000 turbo-alternator and all boilers are used; and because the average number of locomotives in service, about 20, is small. The peak loads are hard on the furnaces and the boiler economy is reduced.

The extension of the road to New Haven, 73 miles, the electrification of 63 miles of freight yards on the Harlem River Branch, and the construction of the New York, Westchester & Boston Railroad, in 1911, required the addition of four 4000 kw. turbo-alternators.

**Reference.**

Coster: Electric Journal, Jan., 1908; E. R. J., Aug. 31, 1907; Murray: A. I. E. E., 1908–9–10–11.

NEW YORK CENTRAL & HUDSON RIVER RAILROAD.

The plants of this company are located on opposite sides of Manhattan Island, the Port Morris station on the East River and the Kingsbridge station on a slip leading from the Hudson River near the load centers of the Harlem Division, and on the Hudson Division. The Kingsbridge station is practically a reserve duplicate plant and is used as a substation.

Each plant now contains 16 of twenty-four 625-h. p. boilers, with Roney stokers; and 4 of six 5000-kilowatt Curtis, 25-cycle, three-phase, 11,000-volt turbo-alternators.

The energy is distributed at 11,000 volts pressure by underground cables and by overhead steel transmission towers to 9 rotary converter substations along the Harlem and the Hudson electric divisions.

The load factor of the plants is only 50 per cent., the routes being short, and the power being used at present for suburban passenger and terminal service. The peak load is only 20,000 kw.

**References.**

S. R. J., Nov. 11, 1905; Sept. 29, 1906; Oct. 12, 1907.

INTERBORO RAPID TRANSIT COMPANY.

The Interboro plants supply energy for the Manhattan Elevated Railroad from the Seventy-fourth Street station, and for the New York Subway from the West Fifty-ninth Street station, on Manhattan Island.

The Seventy-fourth Street station contains sixty-four 500-h. p., B. & W. boilers with Roney stokers, economizers, and superheaters; and eight Allis-Westinghouse, 5000-kilowatt engine-generator units.

The Fifty-ninth Street station contains sixty 600-h.p. B. & W. boilers with Roney stokers at the front and also at the rear of the boilers. Economizers and superheaters are used. The generating equipment consists of nine Allis-Westinghouse 5000-kilowatt engine generators, each with a 5000-kilowatt Curtis exhaust steam turbine with induction generators. The recent introduction of the exhaust steam turbines did not increase the size of the building, but improved the fuel economy 33 per cent. Pennsylvania semi-bituminous coal is used, which has about 14,250 B. t. u. The thermal efficiency of the engine-turbo unit is 20 per cent.

Generators are 25-cycle, three-phase, 11,000-volt. The energy is transmitted at 11,000 volts, to direct-current converter substations. The peak load of the two plants exceeds 177,000 kw.

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## HUDSON & MANHATTAN RAILROAD.

The power plant is well located in Jersey City near the center of the New York City, Hoboken, Jersey City, and Newark load.

The generating equipment consists of two 3000-kilowatt and two 6000-kilowatt turbo-alternators of the vertical Curtis type. Units are installed on a basis of one chimney and four 900-h. p., B. & W. boilers per 6000-kilowatt generator. The present plant is designed for 16 boilers. Green fuel economizers are used for each group of boilers.

Three substations, each containing four 1500-kilowatt, 600-volt rotary converters, have been installed.

Motive power is supplied to 200 motor cars of 320-h. p. capacity each for the most important tunnel and rapid transit service in America.

**Reference.**

E. R. J., March 5, 1910.

## LONG ISLAND RAILROAD.

The power plant is located in Long Island City on the East River advantageous to fuel, and it is near the center of the combined loads of

the Long Island Railroad and the Pennsylvania Tunnel and Terminal Railroad. Thirty-two 564-h. p. B. & W. boilers have Roney stokers. Sixteen duplicate boilers can be added in the present building. Natural draft is used. The cheapest low-grade fuels are burned to advantage in the furnaces. Three 5500- and two 8000-kilowatt turbo-alternators deliver 11,000-volt, 3-phase, 25-cycle energy to transmission lines which distribute energy to many 660-volt converter substations.
The plant can be extended to house 100,000 kw. capacity.

Load peaks in July, 1910, exceeded 16,000 kilowatts; after the Pennsylvania locomotives and Pennsylvania-Long Island motor-car trains were added, in 1910, the load peak increased to 30,000 kw.

**Reference.**

E. R. J., Nov. 4, 1905; October 12, 1907; Gibbs, June 3, 1911.

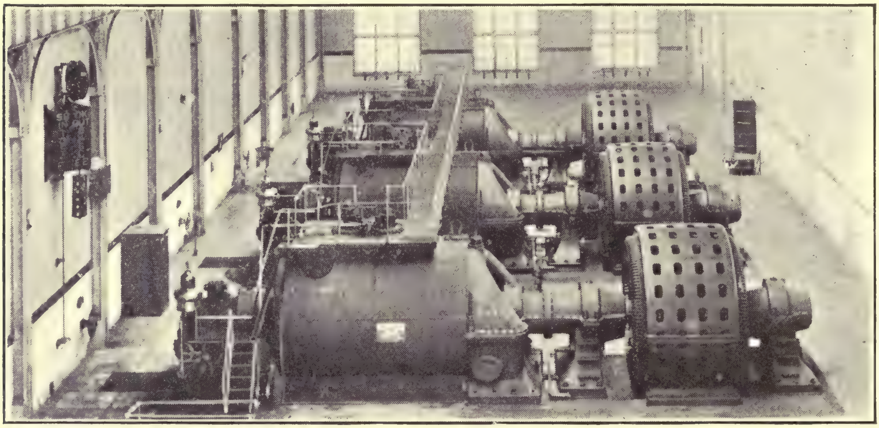

FIG. 180.—PENNSYLVANIA-LONG ISLAND RAILROAD POWER PLANT.
Three 5,500-kilowatt Westinghouse turbines and 25-cycle, 3-phase, 11,000-volt alternators.

## WEST JERSEY & SEASHORE RAILROAD.

The power plant is located on the main line of the electric division of the road between Atlantic City and Philadelphia, at Westfield, 8 miles south of Philadelphia.

The station contains eight 358-h. p. Stirling boilers, with stokers.

Generating equipment consists of four 2000-kilowatt, 6600-volt, 25-cycle, three-phase Curtis turbo-alternators.

The energy is transmitted at 33,000 volts to eight 675-volt converter substations, located along the 75 miles of road, by 70 miles of duplicate 33,000-volt transmission line. The capacity of these substations is 17,000

kilowatts. The loss between the station switchboard and the substation output varies from 20 to 24 per cent.

**References.**

S. R. J., Nov. 10, 1906; Oct. 12, 1907; Gibbs, Ry. Age Gazette, March 25, 1910.

### COMMONWEALTH EDISON COMPANY, CHICAGO.

The main Quarry-Fisk street power plant has these features:

Boiler units are rated 550 h. p. each, but are worked up to 1100 h. p. Chain grate stokers feed coal under the mud drums, reversing the usual direction of flue gas travel. The draft which is produced by steel chimneys is 0.75 inches, water gage. Coal used is a high-volatile, Illinois screening. A boiler efficiency of 63 per cent. is obtained. The coal consumption is 60 pounds per square foot of grate surface per hour.

Steam turbine units consist of ten 12,000-kilowatt and six 14,000-kilowatt units. The maximum output is 184,000 kilowatts on peak load in winter. Six 20,000-kilowatt turbines were ordered in 1910 for its new Northwestern power plant. The economy of the present plants is stated to be 28,000 B. t. u. per kw.-hr.

Energy is sold to every railway which hauls electric trains in Chicago, at $15 per kw-year of maximum demand, plus 0.4 cent per kw-hour.

### TWIN CITY RAPID TRANSIT CO., MINNEAPOLIS.

The steam plant has the following equipment:

Twenty-eight 600-h. p., B. & W. boilers, with 150° of superheat, 175 pounds pressure, which on 1-inch draft, operate regularly at 1100-h. p. capacity; two 3500-kilowatt Allis-Corliss vertical engines; two 5000-kilowatt, and two 14,000-kilowatt Curtis steam turbo-alternators.

In the rebuilding of this plant, erected in 1902, two 16-foot by 220-foot tile and brick chimneys have been replaced by four 14-foot by 263-foot steel stacks, lined thruout with 4 inches of concrete; the Roney stokers which are suitable for eastern coals were replaced by chain grate stokers which burn either northern Illinois or Youghiogheny screenings to advantage; grate areas have been increased 20 per cent.; coal is now stored and flooded in concrete cells in place of being allowed to deteriorate in huge piles; cast iron fittings were replaced by steel fittings and nickel-bronze valve seats for the superheated steam; and the four vertical cross-compound, condensing Allis-Corliss engines are now being replaced by 14,000-kilowatt 5-stage and 6-stage vertical Curtis steam turbines. Storage of heat in water under full pressure is planned for peak loads.

Steam consumption of the steam engines is 22 pounds per kw.-hr.; of the small steam turbines, 20 pounds; of the 14,000-kilowatt, 14 pounds.

The peak load at the power plant is 35,000 or 50 kilowatts per car.

Two water power plants, with 16,000 kilowatts capacity, near the steam plant, carry the body of the railway load.

Power has been distributed since 1897 by means of underground 13 200-volt, paper-insulated cables, to 11 converter substations in Minneapolis and St. Paul, and long interurban lines. The efficiency between the alternating-current bus and the car is 60 per cent.

Car equipment consists of eight hundred 45-foot, 22- to 25-ton, steel-framed motor cars, each equipped with from 200 to 300 h. p. in motors; and there are twenty-two 45-foot motor cars in heavy freight service.

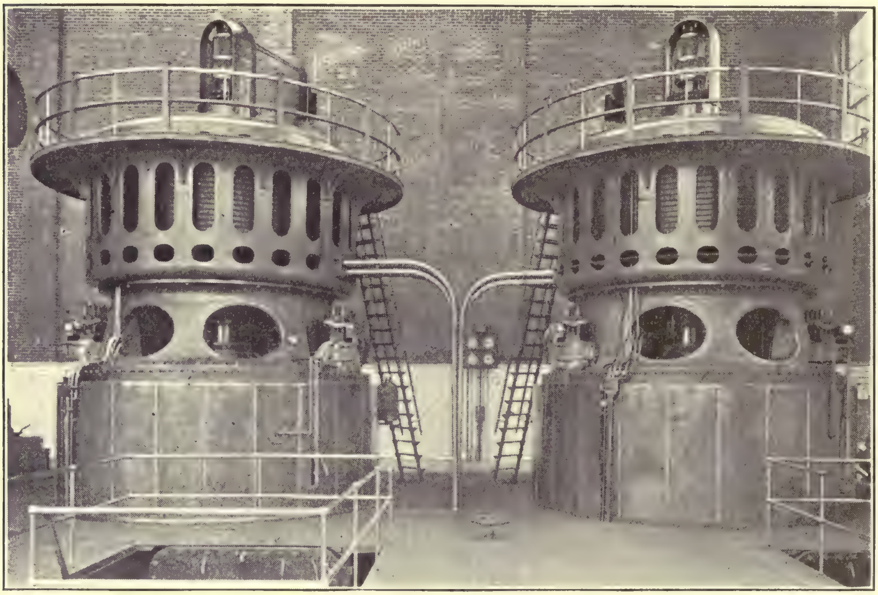

FIG. 181.—TWIN CITY RAPID TRANSIT CO. 5000-KW. CURTIS STEAM TURBO-ALTERNATORS. 33-cycle, 13,200-volts.

The 33-cycle, three-phase system was chosen in 1896, at which time seven 700-kilowatt alternators and five 600-kilowatt 660-volt railway rotary converters were purchased in connection with the equipment of the first water power plant. Plans were made to combine all electric railway and lighting power plants and interests, and the 33-cycle system was not only suitable for the railway rotary converters, but for the arc and incandescent lighting in the city of Minneapolis. Neither 25 nor 60 cycles would have been satisfactory for the combined service.

## MILWAUKEE NORTHERN RAILWAY.

This power plant is located at Port Washington, near the middle of the company's 58-mile road between Milwaukee and Sheboygan, Wis.

It is one of the very few successful gas producer and gas engine plants. There are four Loomis-Pettibone bituminous gas producers which burn a cheap grade of Hocking Valley bituminous slack coal and deliver gas with about 125 B. t. u. per cubic foot. There are three 1250-kilowatt, 32x42, 4-cylinder, twin, tandem, horizontal, double-acting Allis gas engines, each direct-connected to 25-cycle, three-phase, 405-volt, 107-r. p. m. alternators. Electric power is furnished, thru transformers and rotary converters, to a high-grade interurban railway.

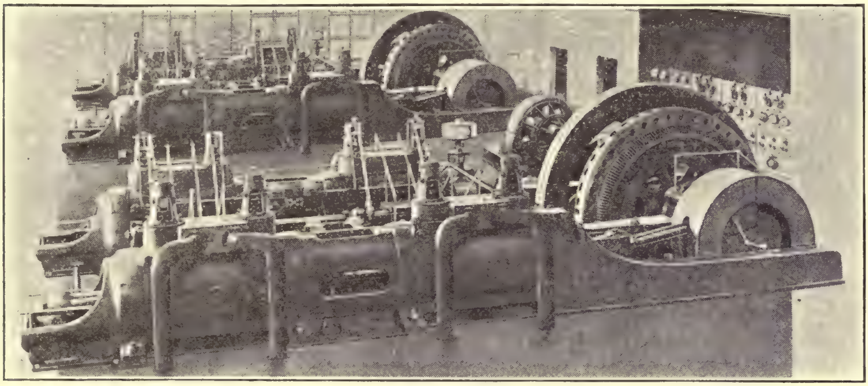

FIG. 182.—MILWAUKEE NORTHERN RAILWAY POWER PLANT.
Two 1250 kilowatt gas engines and 25-cycle, 3-phase, 405-volt, 107 r.p.m. alternators, built by the Allis-Chalmers Company.

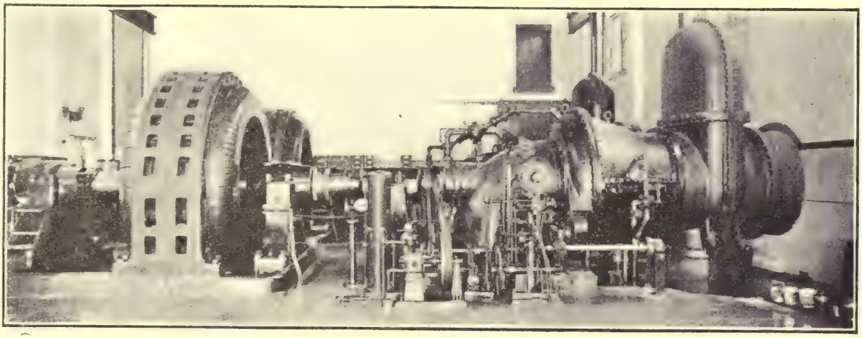

FIG. 183.—GREAT NORTHERN RAILWAY—CASCADE TUNNEL POWER PLANT EQUIPMENT.

## GREAT NORTHERN RAILWAY.

The water power plant used to propel trains thru the Cascade Tunnel is located 30 miles east of the tunnel. The plant was designed by Mr. J. T. Fanning of Minneapolis.

The equipment consists of three 4000-h. p. horizontal Smith turbines,

each direct-connected to a 2500 kv-a., 6600-volt, 25-cycle, 375 r. p. m. alternator. The units have a large overload capacity, for train service. Four transformers raise the voltage from 6600 to 33,000 volts. Each transformer is rated 844 kilowatt but will operate at 100 per cent. overload for 1 hour with a reasonable rise in temperature.

The head of water is 185 feet. To equalize the pressure due to friction and inertia of the water in an 8.5-foot stave pipe line, 11,000 feet long, between the dam and the power plant, a 360,000-gallon steel tank is connected to the foot of the pipe line. The water is lowered 12 feet when a 2000-ton train is accelerated, and, when the load is thrown off, the water is relieved by an inside overflow pipe having a funnel-shaped head. The regulation of the suddenly applied 5000-h. p. load was the hardest of the many problems involved. About 21,000 tons of water moving at the rate of 8 to 10 feet per second cannot be retarded quickly. The surge tank takes care of the work safely and without waste of large amounts of energy or of water.

## LONDON ELECTRIC RAILWAYS.

The Chelsea power plant of the company in London is one of the largest electric railway plants in the world. It feeds the Great Northern, Piccadilly, and Brompton Railway; the Charing Cross, Euston & Hampstead Railway; Baker Street and Waterloo Railway; Metropolitan and District Railway; and other railway and power loads.

Eight 5500-kilowatt Parsons steam turbo-alternators are installed.

The alternators are 33-cycle 11,000-volt units and feed common 600-volt rotary converter substations.

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*This page is reserved for additional references and notes on power plants for railway train service.*

## CHAPTER XIV.

# PROCEDURE IN RAILROAD ELECTRIFICATION.

**Outline.**

**Essential Considerations:**

Reasons for procedure, impracticable electrifications, opportunities in general, opportunities on mountain grades, electrification of established steam roads,

**Collection of Data:**

Maps and profiles, train service, steam locomotives, freight and passenger cars, operating expenses, limits on the work.

**Deductions from Data:**

Analysis of the operation of the road, energy required for trains.

**Cost of Electrification:**

Power plants, transmission and contact lines, substations, electric motors, cost of steam equipment of steam roads.

**Cost of Electrifications Completed.**

**Errors to be Avoided:**

Amount of equipment, freight service, number of substations, maintenance of both steam and electric service, lack of appreciation of steam railroad problems.

**Electrical Engineers for Railroads.**

**Literature.**

# CHAPTER XIV.

## PROCEDURE IN RAILROAD ELECTRIFICATION.

### IN GENERAL.

The electrification of railroads demands a consideration of the reasons for utilizing electric power, and requires information on the methods, systems, and practice by which definite results have been accomplished. This information has already been gathered, in some measure, in the previous chapters.

### ESSENTIAL CONSIDERATIONS.

Economy is the primary consideration for procedure in electrification. The objects in view in electrification are to save coal rather than to gain relief from smoke; to accelerate a train economically, not at two-thirds cut-off; to gain speed rapidly so as to reduce the losses in braking which accompany high maximum speeds; to avoid friction and excessive weights; to prevent waste in steam when heavy freight trains are hauled up the grades at good speed; to use rotary motion in place of reciprocating, because track pounding is decreased; to reduce the cost of labor and maintenance per ton-mile; to render efficient service at the congested freight and passenger terminals; to save time in classifying of cars; to keep the yards cleared so that the freight does not accumulate; and finally to furnish all practical facilities for safe and concentrated working at terminals.

Gross and net earnings are radically increased when electric transportation methods are used, which fact cannot be questioned after a consideration of the results which were outlined in Chapter III. Financial considerations always demand first attention. Electrification hinges on the *extent* of the returns which can be made from a given expenditure.

Financial reasons are generally combined with physical. Electricity has already furnished a solution of difficult and important transportation problems. Developments and applications have now furnished the financial experience needed. Electric passenger trains, to be profitable, require unlimited tractive effort for rapid acceleration and for grades. Suburban trains, interurban roads, and local railways, which are feeders and distributors for railroads, have increased their net earnings by the adoption of electric service and methods. Electric power for tunnel service, with steep grades and heavy traffic, furnishes both the physical and the economical results desired, and these results are very much better than with steam traction.

Physical and financial advantages of electric power for train haulage were discussed at length in Chapter III, and the physical and financial advantages of motor cars and of electric locomotives were considered in Chapters VI and VII.

The reasons for the electrification of tunnels, subways, and terminals are obvious. Elevated roads now operate heavier electric trains, at higher speeds over light supporting structures. Motor-car trains have quickly superseded suburban steam trains, because the former are more flexible, and frequent stops can be made with economy. Water power was a factor in the electrification of roads near Albany, Buffalo, Grand Rapids, Minneapolis, Spokane, Seattle, Denver, Los Angeles, in the mountains, and elsewhere. The solution of many of the problems, in real heavy transportation, required an increase in capacity, *i. e.*, drawbar pull and speed. The reason why electric traction for trunk lines is to follow, for freight and passenger traffic, is because electric traction has inherent physical advantages, and can handle traffic comparable with existing or heavier service with higher economy.

A broad policy exists on the part of almost every railroad to use improved methods in transportation wherever it pays.

**Reasons for Procedure in Electrification are now Summarized:**

Economy of operation on trunk lines. Saving in power, wages, and maintenance.

Cheaper power from fuels; lignite and culm fields, low grades of coal. Blast furnace or coke gas for engines. Natural gas for boilers, or for engines.

Cheaper power from water power, for mountain grades and ordinary roads.

Capacity, drawbar pull and speed, for rapid transit and dense passenger service.

Economy and capacity on mountain grade railroads and in heavy freight haulage.

Smoke nuisance, exhaust noise, and fire risk avoided; tunnel and switching railways. Elevated railways in large cities. Suburban and resident district railways. Mill, factory, dock, and industrial railways.

Compulsory, for safety and comfort, at railroad terminals and yards.

Passenger and freight traffic on city streets, with electric motive power.

Financial situation relieved. Lost traffic regained; new business induced.

Prevention of competition; control of railway situations.

Policy of general improvement, local or national; water power vs. importation of foreign coal; standardization for state railways in Europe; saving in time of passengers and hastening of freight; passenger service made attractive and enjoyable.

Demand for frequent and rapid suburban service, "resulting both from the increase in population and the education which the public has now received; and the necessity for increasing the carrying capacity and speed of trains, without excessive capital expenditure." *Dawson:* re. London, Brighton & South Coast.

Promotion and development of roads, lands, water powers, etc.

These, then, are the reasons which cause rai road engineers to study the subject of electrification attentively, to think out the best methods of procedure in the application of electric power and, at an opportune time, to act for railroads. Specific cases are now cited.

REASONS FOR ELECTRIFICATION OF STEAM RAILROADS.

| Name of railroad. | Route miles. | Total mileage. | Primary or important reason for use of electric power. |
|---|---|---|---|
| Boston & Maine: | | | |
| Concord & Manchester Division. . | 17 | 30 | Interurban traffic. |
| Hoosac Tunnel. . . . . . . . . . . . . . . . . . | 8 | 22 | Limiting point of service, Fitchburg Division. |
| New York, New Haven & Hartford: New York Division | 35 | 100 | Compulsory for terminal. Economy for dense, long-distance traffic. |
| Harlem River Yards. . . . . . . . . . . . | 13 | 63 | Economy in yard service. |
| Manhattan Elevated. . . . . . . . . . . . . . | 38 | 119 | Lost traffic to regain; economy in operation. |
| New York Central. . . . . . . . . . . . . . . . | 44 | 150 | Compulsory for terminal service; economy of land; better service. |
| Long Island. . . . . . . . . . . . . . . . . . . . . | 62 | 164 | Dense local traffic. Economy of operation. |
| Pennsylvania Tunnel & Terminal. . . | 15 | 95 | Tunnel grades; city terminals; suburban traffic. |
| West Jersey & Seashore. . . . . . . . . . . | 75 | 154 | Increased earnings for a long route. To forestall a proposed parallel competitor. |
| Delaware & Hudson. . . . . . . . . . . . . . . . . . . . . . . . . . . | | 245 | "Largely a protective measure." |
| Albany Southern. . . . . . . . . . . . . . . . . | 38 | 62 | Water power; interurban lines. |
| West Shore R. R. . . . . . . . . . . . . . . . . | 44 | 114 | "Recognizing the evils of competition." Utilization of existing tracks. |
| Erie R. R. . . . . . . . . . . . . . . . . . . . . . . | 37 | 40 | Competition prevented. |
| Lackawanna & Wyoming. . . . . . . . . . | 25 | 50 | Grades; development of a new road. |
| Wilkes-Barre & Hazelton. . . . . . . . . | 31 | 34 | Grades; development of a new road. |
| Baltimore & Ohio. . . . . . . . . . . . . . . . | 4 | 7 | Tunnel and terminal service. |
| Baltimore & Annapolis. . . . . . . . . . . . | 25 | 35 | Many reasons. See Chapter XV. |
| Grand Trunk Ry., St. Clair Tunnel. | 4 | 12 | Tunnel and terminal service. |
| Michigan Central, Detroit Tunnel . . | 6 | 19 | Tunnel; saving in time. |
| Toledo & Western. . . . . . . . . . . . . . . . | 59 | 84 | Interurban freight service. |
| Cincinnati, George. & Portsmouth . . | 41 | 57 | Improvement of road. |
| Illinois Traction Company. . . . . . . . . | 460 | 560 | New business and interurban traffic. |
| East St. Louis & Suburban. . . . . . . . | 20 | 181 | Coal haulage to and in St. Louis. |
| Chicago, Milwaukee & St. Paul. . . . . | 6 | 20 | Suburban traffic to Evanston, Illinois. |
| Chicago, Burlington & Quincy. . . . . | 4 | 4 | Grades on Black Hills Division. |
| Colorado & Southern . . . . . . . . . . . . . | 64 | 74 | Use of water power for grades on Denver Division. |
| Rock Island Southern. . . . . . . . . . . . . | 52 | 82 | Utilization of waste coal. |
| Fort Dodge, Des Moines & Southern | 70 | 141 | General. |
| Waterloo, Cedar F. & Northern. . . | 30 | 100 | General. |
| Salt Lake & Ogden. . . . . . . . . . . . . . . | 35 | 55 | General serviceability. |
| Spokane & Inland Empire. . . . . . . . | 204 | 287 | Land development; water power. |
| Great Northern, Cascade. . . . . . . . . . | 4 | 6 | Tunnel. |
| Northern Pacific, Everett Division. | 9 | 10 | Competition prevented. |
| Northwestern Pacific. . . . . . . . . . . . . . | 20 | 34 | General serviceability. |
| Southern Pacific. . . . . . . . . . . . . . . . . . | 30 | 100 | Heavy suburban traffic. |
| Pacific Electric. . . . . . . . . . . . . . . . . . . | 40 | 600 | Heavy interurban traffic. |
| Havana Central, Cuba. . . . . . . . . . . . | 50 | 73 | Freight haulage. |
| Mersey Ry., England. . . . . . . . . . . . . | 5 | 10 | Tunnel and to regain traffic. |
| North-Eastern Ry., England . . . . . . | 37 | 82 | Increase in capacity. |
| Lancashire & Yorkshire. . . . . . . . . . . | 40 | 82 | To regain lost traffic; to furnish frequent and economical service. |
| London, Brighton & South Coast. . . . . . . | 23 | 62 | Competition; loss of traffic. Capacity for dense traffic. Best use of investment. |
| Swedish State . . . . . . . . . . . . . . . . . . . | 93 | 110 | Water power; economy in freight haulage. |
| Paris-Versailles . . . . . . . . . . . . . . . . . | 11 | 16 | Tunnel grades near terminals. |
| French Southern Ry. . . . . . . . . . . . . . | 65 | 75 | Water power; mountain freight haulage. |
| Bernese Alps Ry., . . . . . . . . . . . . . . . | 52 | 55 | Water power; mountain grade haulage. |
| Prussian State Rys. . . . . . . . . . . . . . . . . . . . . . . . . . | | 108 | General economic development. |
| Swiss Federal Rys. . . . . . . . . . . . . . . . | 38 | 52 | Water power; grades; tunnels. |
| Italian State Rys. . . . . . . . . . . . . . . . . | 141 | 250 | Water power; mountain grade haulage. |

In each case there was a combination of reasons.

**Impracticable electrifications** must be considered, to avoid waste of money and effort, particularly so while there are so many good opportunities for the advantageous application of electric traction. Impracticable cases, when analyzed, are generally shown to be those wherein the investment for the large electrical equipment cannot be used regularly.

Traffic may not be sufficiently heavy to give body to the load. There is no economy operating on a short line; or of making large investments for a small amount of work.

Railroads must have 10 trains each way per day or haul 1,000,000 ton-miles daily, per 100-mile division, before electrification is practical.

Electric power should not be used on a small scale, "to try it out," because economies to overbalance the fixed charges cannot be effected; nor is it necessary any longer to experiment with equipment. Skilled and experienced men are now available. Calculations can be predicted with accuracy as in other lines of engineering.

Traffic may not be sufficiently regular. Electrification for passenger service alone, from the terminal of a city of less than 300,000 people, is financially impracticable. The freight and switching service should always be added so that during the 24 hours of the day, the entire investment may be utilized steadily. Traffic cannot be regular with short roads. Electrification is impracticable for an intermittent traffic, badly bunched business, heavy Sunday excursion and light week-day service, infrequent and heavy passenger and freight service; or for irregular train service on long grades. Large power plants, with good load factors, are necessary for economy. Above all, the power plant, power transmission lines, and electrical equipment must be utilized regularly to reduce the fixed charges per ton-mile or per train-mile.

Energy required for trains may not be capable of being generated at a reasonably low sum per kilowatt hour, on account of the traffic limitations, a low load factor, lack of condensing water, etc.

**Opportunities generally arise** for the use of electric power, or are favored by those situations and conditions where work can be done effectively and economically, and where the fixed charges on the added electrical equipment are a small portion of the operating expenses. Opportunities of this nature are developed on:

City, suburban, and interstate railways.

Interurban roads on an existing railroad right-of-way.

Railroads with light bridges or structural limitations.

Dense traffic with frequent light or heavy trains.

Roads which are worked up to their track capacity.

Locations where cheap water power or coal or gas is available.

Roads which use large quantities of high-priced coal.

Roads where the water supply for locomotives is bad or expensive.

Branch roads when electric power is used on the main line.

Parallel roads, already built to obtain and retain new traffic.

New lines, to prevent competition or to lower rates.

Situations where by-products of electrification can be saved as when the railroad load can be smoothed out by the use of live steam for power, pumping, light, production of ice, etc., and of exhaust steam for heating, during the hours of non-peak load.

Terminal railways to reduce the number of train movements; to handle traffic in materially less time; to prevent congestion; to utilize the expensive real estate efficiently, to superimpose tracks, offices, and warehouses, over the tracks, sub-tracks, etc.

Roads which can carry out electrification on a large scale.

Wherever more than 250 h. p. are required per mile of single track, the electric locomotive can replace the steam locomotive with decided economy and advantage. *Leonard.*

Power equipment used per mile of single track, given in a table on Steam-Electric Power Plant Installations, page 427, for many railroads is over 1000 h. p. per mile of single track.

**Mountain-grade electrification** deserves consideration where there is heavy traffic because of the physical and financial advantage to be gained. The work done up to this time has been limited.

Steam locomotives of the largest size, including many Mallet compounds, are now used. In mountain grade service the steam locomotive is unsatisfactory because:

a. Weight per h. p. output is twice that of electric locomotives and the excessive weight destroys track, trestles, embankments, and roadbed. Curves must be well crowned to prevent a runaway train from jumping the curves and, at slow speeds, the well-oiled flanges of drivers, on 10- to 14-foot rigid wheel bases, grind hard against the rail head. Curves are soon destroyed by this friction.

b. Complications exist in articulated locomotives with their steam connections and the multiplicity of mechanical parts. The friction at operating speeds is high and exceeds 30 pounds per ton. Many Mallets will not drift down a 1.7 per cent. grade.

c. Maintenance expenses per train-mile are enormously high, and are out of all proportion to the advantage gained. Excessive temperature strains are produced in the fire boxes and tubes. The cost of maintenance in winter is from 15 to 35 per cent. greater than the cost in summer. The great length, weight, and vibration result in enormous strains, followed by leakage and breakage, and time lost on the road.

d. Speed is slow because the capacity to haul heavy trains is limited by the square feet of heating surface in the boiler. Traffic is de-

layed by slow speeds, the mileage is reduced, and the equipment, track, and cars are thereby increased. The investment is not utilized to best advantage. The 250-ton Mallet, with two firemen, and an overloaded furnace, hauls only 800 to 900 tons trailing load up 2.2 per cent. grades and then at a speed of only 10 to 8 miles per hour.

e. Radiation of heat and the stand-by losses, on the cold windy divisions, require a large proportion of the total coal used. The locomotives work hard for a short time and are then idle for many hours.

f. Economy of Mallet compound steam locomotives in mountain service is low because the steam is used at about two-thirds stroke, and because condensation and friction are excessive. See data on Southern Pacific and other Mallet locomotives in Chapter II.

Electric locomotives in mountain grade service are:

a. Light in total weight, and in weight per linear foot.

b. Simple in construction, and somewhat automatic in operation.

c. Maintained at a much lower cost per train-mile run, because of fewer parts and lower friction.

d. Efficient, in that there are no stand-by losses.

e. Economical in the use of steam at the central steam power plant; economical in the cost of power when cheap low-grade coals are available, or when water power is available in the mountains.

f. Safe in tunnel operation, safety being promoted by regeneration of electrical energy in braking on the down-grade. Wrecks are fewer.

g. Capable of hauling the heaviest trains, not at 8 m. p. h., but at 15; not with one 250-ton locomotive concentrated at the head or behind the train, but with two 125-ton locomotives controlled by one engineman and his assistant. While the capacity of the steam locomotive is greatly reduced by cold windy weather, the capacity of the electric locomotive is increased. Capacity, light weight, and economy are combined.

Operation on mountain grades and on ordinary but long grades is an important matter, because the cost of steam service is relatively high. Economies can be effected; the congestion can be avoided; the single track can be used to better advantage; the cost of track and locomotive maintenance can be reduced; the wrecks can be decreased; and the high wages paid per ton-mile can be reduced. The limit on the loads to be hauled, and on the speed, can be placed at the electric power plant. Railroads on heavy mountain grades can adopt electric traction to best advantage, when the traffic is heavy and frequent, and the grades are long and steep.

The following table compiled from an Interstate Commerce Report, and from other sources, shows the character and the importance of the work on mountain grades.

FREIGHT HAULAGE BY STEAM LOCOMOTIVES ON MOUNTAIN GRADES.

| Name of railroad. | Name of mountain or grade. | Length in miles. | Grade in %. | Trains daily. | Tonnage per train. | M. p. h. on down-grade. |
|---|---|---|---|---|---|---|
| Baltimore & Ohio.... | Sand Patch, Pa.... | 19.5 | 1.70 | 60–100 | 1800–3000 | 15–16 |
| | Grafton, W. Va... | 20.0 | 2.20 | 20–40 | 1800–2000 | 10–14 |
| Buffalo, Rochester & Pittsburg. | Bingham.......... | 7.8 | 1.50 | 60–80 | 2250–2500 | 13–15 |
| | W. Valley......... | 5.7 | 1.70 | ........ | 1500–1800 | 12–13 |
| Delaware, Lackawanna & Western. | Clark Summit .. | 7.3 | 1.48 | 60–100 | 2000–2300 | 14–16 |
| | Pocono............ | 17.0 | 1.52 | ........ | 1500–2500 | 14–15 |
| Erie R. R............ | Cowanda.......... | 4.6 | 2.50 | ........ | 1000–1400 | .......... |
| | Big Shanty........ | 6.4 | 2.45 | ........ | 1600–1750 | .......... |
| Delaware & Hudson.. | Carbondale-Forest C | 6.0 | 1.36 | ........ | 1400–1500 | 8–10 |
| | Forest City Ararat.. | 14.0 | 0.81 | ........ | .......... | .......... |
| | Ararat-Oneonta .. | 75.0 | 1.00 | ........ | .......... | .......... |
| Pennsylvania......... | Bellwood.......... | 8.2 | 3.31 | 60–100 | 1400–2200 | 14–16 |
| | Tryone............ | 10.0 | 3.00 | ........ | 1600–2000 | 18–20 |
| | Dunlo............. | 4.5 | 3.50 | ........ | 1500–1700 | 12–13 |
| | Gallitzen.......... | 11.0 | 1.70 | ........ | 1500–2000 | 14–20 |
| | | | to 2.38 | ........ | .......... | .......... |
| | Pottsville.......... | 4.5 | 3.13 | ........ | 700–1000 | 11–19 |
| | | 6.5 | 1.19 | ........ | .......... | .......... |
| Western Maryland .. | Cumberland....... | 20.0 | 1.70 | ........ | .......... | .......... |
| Chesapeake & Ohio... | Thurmond-Ronceverte. | ........ | .36 | ........ | .......... | .......... |
| | Ron.-Allegheny ... | 13.0 | .57 | ........ | 3000 | 10–12 |
| Philadelphia & Read. | Flackville......... | 5.7 | 3.50 | ........ | 1000–1500 | 11–13 |
| Duluth, Missabe & Northern. | Proctor Hill....... | 6.0 | 2.00 | ........ | 15,000,000 tons per year. | .......... |
| Chicago, St. Paul, Minneapolis & Omaha | Hudson, Wisc..... | 1.0 | ........ | 15–22 | 1500–2000 | 15–18 |
| Chicago, Milwaukee & St. Paul. | St. Paul.......... | 1.0 | 1.50 | 30 | 900–1500 | 10–12 |
| Great Northern....... | St. Paul.......... | 1.0 | 1.65 | 150 | 1300–1520 | 10–12 |
| | Butte Hill......... | 12.0 | 2.20 | 10 | 1200–1850 | 17–18 |
| | Cascade........... | 32.0 | 2.20 | 10 | 1000–1500 | 15–20 |
| Chicago, Milwaukee & Puget Sound. | Bitter Root....... | 4.0 | 2.00 | ........ | .......... | .......... |
| Colorado Midland..... | Hagerman......... | 38.2 | 3.13 | ........ | 760 | 18–20 |
| | Ute Pass.......... | 9.5 | 3.50 | ........ | 500 | 18–20 |
| Denver & Rio Grande | Bingham......... | 9.0 | 2.00 | ........ | 600 | 18–20 |
| | | 2.0 | 4.00 | ........ | .......... | .......... |
| | | 14.0 | 2.20 | ........ | 1800 | .......... |
| | Soldier Summit...... | 7.0 | 4.00 | ........ | 650 | .......... |
| | | 18.0 | 2.46 | ........ | 850 | .......... |
| | Sunny Side........ | 10.0 | 2.50 | ........ | 1800 | .......... |
| | Tennessee Pass .... | 21.0 | 3.00 | ........ | 800 | .......... |
| Atchinson, Topeka & Santa Fe. | Tehachapi ....... | 30.8 | 2.20 | ........ | 1000–1500 | 15–19 |
| | Glorieta........... | 9.8 | 3.00 | ........ | 950–1000 | 15–22 |
| | Raton Mt......... | 13.0 | 3.50 | ........ | 1000 | 19–22 |
| | | 15.0 | 2.20 | ........ | 1000 | 19–12 |
| Canadian Pacific...... | Phoenix........... | 4.0 | 4.50 | 16 | 500–800 | 5–8 |
| Northern Pacific...... | Livingston........ | 11.0 | 2.20 | 12 | 1400–1600 | 10–15 |
| | Helena............ | 16.0 | 2.20 | 10 | 1600–1800 | 13–18 |
| | Helena............ | 3.0 | 1.61 | 10 | 1600–1800 | 13–18 |
| | Missoula.......... | 15.0 | 2.20 | 12 | 1600–1800 | 12–18 |
| | Cascade........... | 10.0 | 2.20 | 18 | 1000–1500 | 16–21 |
| | Cascade........... | 6.0 | 1.42 | 18 | 1000–1500 | 15–21 |
| Butte, Anaconda & P. | Butte............. | 4.8 | 2.50 | 20 | 1000–1100 | 5–8 |

FREIGHT HAULAGE BY STEAM LOCOMOTIVES ON SOME MOUNTAIN GRADES. (Continued.)

| Name of railroad. | Name of mountain or grade. | Length in miles. | Grade in%. | Trains daily. | Tonnage per train. | M. p. h. on down-grade. |
|---|---|---|---|---|---|---|
| Butte, A. and Pacific. | Butte-Anaconda... | 8.0 | .41 | 8 | 3400–3600 | 12–14 |
| | Anaconda.......... | 6.7 | 1.16 | 18 | 1900–2000 | 6–10 |
| Oregon Short Line.... | Rock.............. | Many. | 2.20 | Few. | .............. | .......... |
| Southern Pacific...... | Siskiyou........... | 18.0 | 3.30 | Many. | 800–1200 | 11–12 |
| | Shasta............. | 9.3 | 2.20 | ........ | 900–1400 | 12–15 |
| | Tehachapi......... | 30.0 | 2.20 | ........ | 800–1500 | 14–20 |
| | Sierra Nevada..... | 70.0 | 2.20 | Many | 1050–1300 | 14–20 |
| | Roseville-Summit.. | 87.0 | 1.50 | Many | 1000–1200 | 7–10 |

Speeds noted are from trainmen's time tables and show the maxiumm allowed on the down-grade, which speed is about one-half of the up-grade speed. Tonnage is the ordinary freight train load behind the head locomotive. Two locomotives are common per train.

See profile of grades of important railroads in Ry. Age Gazette, July 21, 1911, p. 111.

**Electrification of established steam roads** can be accomplished to much better advantage by steam railroads than by new, independent, parallel electric roads, for the following seven reasons:

Money can be borrowed by steam roads at lower rates, on a large scale, and with minimum delay when an existing road banks its reputation, past and future, on the outcome.

Traffic already exists and haulage of freight and passenger trains can be clearly estimated. The economies to be effected are more definitely predetermined. The records of traffic and interchange are actual, and what is needed for haulage can be carefully studied.

Roadbed is completed, and electrification simply means the better use of the investment, yet without complication for either steam or electric service. Bridges, terminals, and buildings may be utilized.

Car equipment is already in service, and ready for haulage with electric locomotives.

Organization is perfected, and experienced railroad managers, superintendents, dispatchers, and well-trained employees govern; not a set of new, unorganized railroad men.

Investment is required for electrical equipment only, or approximately 20 per cent. of the total cost of the existing steam railroad. A new road must obtain a complete outfit—terminal, right-of-way, roadbed, equipment, offices, organization.

In competition, the steam road which uses electric traction can get and also keep the business from new or old competing roads.

## COLLECTION OF DATA FOR PROCEDURE IN ELECTRIFICATION.

In the engineering work for the electrification of roads, the chief engineer, the electric traction engineer, the superintendent of motive

power, and others, usually make a preliminary report to the manager or president on the use of electric power for train haulage over a division.

The advantages of electric traction are not argued by these men. They have already in mind, for the specific case under consideration, some definite physical results to be gained, or which are needed, to facilitate the handling of traffic.

The work to be done is first outlined, and the limits and character of the work are specified. In the procedure which follows, steps are taken to determine, in a logical and definite way, the cost of the electrification and the *extent* of the financial advantage to be gained.

Data are at once required for a study of the situation. Most of these are available at the railroad office, but some of the facts and working conditions must be obtained from inspections along the division; and the valuable experience of the superintendents, master mechanics, division engineers, and others in charge of operation, maintenance of ways, and of construction, is to be used. If the road is not already in operation, the data cannot be obtained directly, and conditions on many similar roads must be studied, and predeterminations must be made. The experience of other roads is always to be obtained.

Information is generally collected on the following:

1. Maps, profiles, locations, stations, grades, curves, general construction, rails used, trestles, bridges, tunnels, sidings, connecting points, yards, shops, and terminal points where engines and crews are changed.

2. Train service, the character, volume, and direction of existing and new traffic, and changes which are desirable in methods of working. Information is needed on the number and weight of all trains; on the average and the maximum number of trains, on the suburban traffic, on the intermittent work, fish and silk trains, harvest and state fair business; on the direction of ore, coal, grain, and lumber traffic; on the prevailing direction of empty cars; and on the terminal freight and yard service. The traffic sheets for each class of service are necessary to get the number of trains, number of cars, and weight of each train.

Speeds of trains—the scheduled and maximum speeds. The speed records of each type of train, in each direction, are to be obtained from a Boyer or Shalter recorder.

3. Characteristics of the steam locomotives used, as outlined in Chapter II, and a classification of the number used on each division, the heating surface, grate surface, coal and water used, cylinders, distribution of weights, and the outline drawings.

4. Freight and passenger car data, in general; and details on the truck equipment, if rapid transit at terminals is involved.

5. Operating expenses, particularly the kind, source, and cost of different fuels, the costs per ton-mile and per train-mile for each class

of service; the coal and water for switchers and not tests alone, but averages.

6. Maintenance and repair accounts for each service.

Other data will be required for consideration of details and for the particular problems considered.

Limits must be placed on the engineering work involved, because a clean-cut report is required on the specific work under consideration. Too many details and side issues often encumber and retard progress in forming plans and recommendations.

### DEDUCTIONS FROM DATA.

**An analysis** of the operation of the railroad must naturally follow. Broad problems are outlined first. The relative extent of each service, the relative cost, and the net profits, are always involved. The real nature of the business of the road, and of the traffic, is considered. An estimate of the rate of growth, in the past and for the future, is made.

Lower cost of roadbed, shorter routes; increased capacity of road; cheaper fuels, coal mines, or water powers which are available; use of exhaust steam in winter; electric power and light for different shops, elevators, pumps, manufacturing plants; street railways, branch lines, and interurban feeders; joint use of power plant by several railroads, etc., each receives consideration. The financial and physical results from operation of other roads are analyzed.

**The energy required for trains** now receives consideration, as outlined in Chapter XI. The application to the problems of the particular road are made, and the power data are analyzed.

a. Train sheets are drawn for the proposed service.

b. Tractive effort curves are made for each type of train, showing the friction at different speeds, the acceleration rates of different trains, tractive effort for grades, and for a varying number of freight cars or coaches in ordinary trains. Switching service receives consideration.

c. Speeds to be used must be settled.

d. Power required for each train is now plotted, using first m.p.h. and then time as the base, and mechanical h. p. as the ordinate of all curves. (The requirements for ordinary service exceed 100 kilowatts per mile of single track; and 40 watt-hours per ton-mile.)

e. Load diagrams of all trains are plotted on one sheet with time as a base and h. p. or kilowatts as the ordinate. On this diagram all losses are added. The integrated curve is used to determine the total load at any time of the day, and the energy required.

f. Distribution of the energy and the power required along the railroad divisions, substations, etc., now receive extended consideration. Transmission lines, feeders, contact lines, control circuits, maximum number of trains between substations, and other details of the electric power installation are tabulated and plotted.

## COST OF ELECTRIFICATION.

Cost of electrification is an important subject, because the minimum cost for a suitable construction, and maximum economy in operation, are the essentials in transportation. High cost of electrical equipment is one of the chief handicaps which now prevents the general introduction of electric traction on railroads. The cost of individual items is quite valueless unless there is a clear understanding of the relation of the variables which are involved.

The cost of electrification depends primarily upon the following:

1. Density of traffic to be handled.

2. Weight of individual train units, the speeds, the grades, the reliability desired, and the amount of traffic to be interchanged.

3. Length of the route and tracks to be electrified. Length of route affects the load factor of the power plant and the best utilization of transmission lines. Length affects the cost of electrification per mile of track.

4. The electric system employed for the service.

The cost of electric traction equipment to be used is found to vary between the following limits:

| | |
|---|---|
| A. Power plants, | 25 to 40%, average 30% |
| B. Lines and substations, | 40 to 60%, average 50% |
| C. Motor equipment, | 15 to 25%, average 20% |

A. **Power plants** are either steam or hydroelectric, since the cost of gas engine equipment is now prohibitive. The cost varies from 25 to 40 per cent. of the total cost of electrification, depending, in the plant, largely upon the load factor, and relative cost of B and C, which in turn vary largely with the distance and the density of traffic.

Turbines, three-phase alternators, transformers, and switchboards require about the same type, size, voltage, and arrangement, for each electric system, *i.e.* they are not affected by the system.

Direct-current, 600- or 1200-volt systems generally require greater power and more energy than other systems because of the larger losses in contact lines and rotary converter substations. Single-phase systems may require the same kv-a. capacity and if two single-phase circuits of three-phase alternators are used, may require as much electric generator capacity as other systems; but the boiler and turbine equipment required for the single-phase system is decidedly less than for other systems because of the small transmission and substation losses. Three-phase systems require a decidedly larger power plant equipment where grades are encountered in ordinary rolling country on a long division of a common railroad, because the two efficient speeds commonly used cause greater fluctuations in the load. In order to decrease the amount and cost of equipment per ton-mile hauled, it is essential that the load factor, or ratio of the average load to maximum load be high.

B. **Line and substation** cost for a given density of traffic varies from 40 to 60 per cent. of the total cost of electrification.

Direct-current systems using 600- or 1200-volts require expensive contact lines and rotary converter substations, and are thus handicapped for main line railroading. Substations with men to operate them will not be installed where they can be avoided.

Single-phase systems without substations, or with infrequent substations and without attendants, require the minimum expenditure. Overhead contact lines and feeders are decidedly less expensive than the overhead or third-rail contact line and feeders for a 600- or 1200-volt direct-current system. The impedance loss per mile at 25 cycles for one 4/0 trolley and two 100-pound track rails is 0.55 ohms. With an ordinary train requiring 2000 kv-a. the 11,000-volt contact line loss is only 1 per cent. per mile, per train. Therefore, for heavy traffic, the number and cost of transformer feeding substations and the contact line cost and losses are greatly reduced.

Three-phase systems with 3000 volts between the two trolleys as used in Europe, or 6000 as used in the Great Northern Tunnel, are expensive because the cost of two trolleys, insulation, and installation are about twice as much as for the single-phase system.

If catenary construction, parallel to the two trolleys, is employed for safety and for mechanical reasons, the cost of three-phase, two-trolley contact lines is greatly increased. The contact line loss with an ordinary train requiring 2000 kv-a., and with 6000 volts between the contact lines, is 3 per cent. per mile, per train. With 3000 volts between the conductors, the contact line loss is 12 per cent. per mile, per train.

The drawbar pull of three-phase motors varies inversely as the square of the voltage applied to the motor. For example, the small loss of 12 per cent. in the voltage to the motors, which may be expected, means a decrease of 23 per cent. in the drawbar pull; it is therefore essential that substation transformers be frequent.

**Transformers** in substations, or on locomotives and cars, cost less in single-phase units than in three-phase units, particularly so in large sizes. The use of 3000 volts directly on the stator of a large three-phase locomotive motor is practical with careful construction; while with 6000 or 11,000 volts on the line, lower voltages are required on the stator of three-phase and single-phase motors.

C. **Motor equipments** for electric traction vary in cost from 15 to 25 per cent. of the total cost of electrification.

Shunt-wound, direct-current motors or two-speed, three-phase motors, with transformers, cost most, because with constant-speed working, in ordinary rolling country, the maximum load is decidedly large compared with the average load. They are not used for ordinary railroading, for rapid transit, or for switching yards.

The heating of motor coils varies as the square of the h. p.; that is, if the speed on the level were maintained on a 1 per cent. grade, three times as much power is required as on the level, the heating effect would be nine times as large, altho the duration of the period of heating might be reduced one-half as compared with series motors.

Series motors, either alternating- or direct-current, protect themselves, by slowing down in some measure as the load increases, so that the output from the motor is more or less equalized, and a much smaller investment is required to do an average amount of work.

The weight of three-phase motors is lower, the efficiency is higher, and the cost is lower per rated h.p. than other motors. Three-phase motors have the highest cost, per average h.p. output, in service on ordinary grades in ordinary rolling country. Single-phase motors will weigh 10 to 20 per cent. more than direct-current and three-phase motors, because of the extra alternating-current losses at commutators. A low-voltage rotor in a three-phase or in a single-phase motor does not increase the cost of the motor, and it increases its reliability.

The weight of single-phase motors, assuming it to be 15 per cent. greater than others, may add 5 per cent. to the locomotive weight and 1 per cent. to the train weight. In ordinary freight service it is often necessary to place ballast on direct-current, three-phase, and single-phase locomotives, otherwise the torque of the motors slips the drivers; but in passenger service the minimum weight of motors and locomotives serves to best advantage.

Control of motors affects the cost of motors. Direct-current motors require resistance to reduce the voltage during acceleration, at which time they have a low efficiency. Three-phase two-speed motors have a decidedly low efficiency during acceleration. Single-phase motor control is efficient, simple, effective, and of low cost.

The cost of electrification bears some relation to the total efficiency of the system. It is assumed that three-phase and direct-current motors have higher efficiency than single-phase motors, but the great difference in motor control, contact line, transformer, and transmission line efficiency is in favor of the single-phase system. The total equipment, the amount of power required, and the cost of railroad electrification are the least with the single-phase system in almost all cases.

Interchange of traffic affects the cost of electrification, since some interchange will be required in railroading. The motor equipment can be chosen to run on direct-current terminal lines, and on one trolley of three-phase lines. The additional cost in some cases must be paid, in order to reap the advantages of interchange of traffic.

The cost of electrification of steam and electric railroads is detailed, beginning page 512.

**The cost of equipment of steam railroads** in general may be reviewed. The Minnesota State Railroad Commission, after working 30 months, summarized the cost of reproduction and present value of the railroads, in Minnesota to June 30, 1907, for 8100 miles of road and 10,437 miles of single track, as follows:

COST OF STEAM RAILROADS. STATE OF MINNESOTA.

| Items listed. | Cost of production. | Present value. |
|---|---|---|
| Land for right of way, yards, and terminals | $73,201,757 | $73,201,757 |
| Grading, clearing, and grubbing | 56,006,782 | 56,006,782 |
| Protection work, rip rap, retaining walls | 2,419,292 | 2,419,292 |
| Tunnels | 253,250 | 215,262 |
| Cross ties and switch ties | 17,491,500 | 9,627,539 |
| Ballast | 9,413,351 | 9,413,351 |
| Rails | 33,010,087 | 25,199,668 |
| Track fastenings | 5,936,740 | 4,543,054 |
| Switches, frogs, and railroad crossings | 1,389,363 | 962,741 |
| Track laying and surfacing | 5,340,689 | 5,340,689 |
| Bridges, trestles, and culverts | 19,567,524 | 14,518,834 |
| Track and bridge tools | 201,918 | 151,488 |
| Fences, cattle guards, and signs | 2,768,394 | 1,403,082 |
| Stock yards and appurtenances | 559,896 | 349,759 |
| Water stations, 0.4 per cent | 1,606,164 | 1,144,535 |
| Coal stations, 0.2 per cent | 717,519 | 507,713 |
| Station buildings and fixtures | 5,855,258 | 4,097,249 |
| Miscellaneous buildings | 4,344,681 | 3,403,171 |
| Steam heat and electric light plants | 797,484 | 656,069 |
| General repair shops | 4,123,119 | 2,959,019 |
| Shop machinery and tools | 1,831,671 | 1,484,756 |
| Engine houses, turntables, cinder pits, 0.6 per cent | 2,837,988 | 1,874,436 |
| Track scales | 184,130 | 129,474 |
| Dock and wharves, including coal and ore docks | 6,065,496 | 5,392,960 |
| Interlocking plants | 403,071 | 293,197 |
| Signal apparatus | 155,766 | 126,217 |
| Telegraph and telephone lines and appurtenances | 1,410,574 | 1,065,153 |
| Adaptation and solidification of roadbed | 11,743,007 | 11,743,007 |
| Engineering, superintendence, legal expenses | 12,133,641 | 12,133,641 |
| Locomotives, 4 per cent | 17,090,953 | 12,608,422 |
| Passenger equipment | 6,616,170 | 4,554,442 |
| Freight car equipment | 46,911,106 | 34,068,005 |
| Miscellaneous and marine equipment | 1,370,166 | 908,682 |
| Freight on construction material | 3,635,535 | 3,635,535 |
| Contingencies | 17,869,703 | 17,869,703 |
| Stores and supplies | 5,210,010 | 5,210,010 |
| Interest during construction | 31,261,419 | 31,261,419 |
| Total | $411,735,194 | $360,480,160 |

The cost of the motive-power equipment, steam locomotives, shops, and water and coal stations was only 5 per cent., and the value was only 4 per cent. of the total cost of the steam railroads.

**Cost of the motive power equipment** of steam roads is thus a very small item in the total cost of the road. Assuming that the total cost of a railroad without the motive power is $38,000 per mile of single track, the additional cost for the motive power will be about $2000 per mile.

**Cost of electric motive power and equipment** is usually as follows: Power plants $90 to $100 per kilowatt; contact lines for one, two, and six tracks, $4000 to $7000 per single-track mile, and for yards $1500 to $3000 per single-track mile; locomotives for switching, freight, and passenger service, $20,000 to $45,000 per unit.

Cost of electric power plants, transmission lines, and electric locomotives, runs from $7000 to $12,000 per mile of main line track or $1,500,000 for a 100-mile division having 125 miles of track; yet this is only 11 to 17 per cent., to be added to the total cost of the steam railroad.

There is then a relatively small difference between a steam and an electric railroad so far as first cost is concerned.

A railroad company which considers electrification, determines whether the added interest, taxes, and depreciation of $700 to $1200 per mile of track per annum will be more than compensated by an increase in gross earnings and a decrease in labor, fuel, and maintenance.

Electrification expenditures for central power plants, and the cost with transformers and converters, were detailed under Steam, Gas, and Water Power Plants; in presenting Transmission and Contact Lines, the costs of these were given; and under Motor-car Trains and Electric Locomotives, the cost of the electric motive power equipment was given. The relative cost of these items, and the things which influence the cost, have just received consideration. The power plant costs are not variable. Lines and substations for power distribution form about 50 per cent. of the total cost of electrification, and this subject therefore requires the greater study.

The cost of electric locomotives with their power plant, shops, and inspection sheds is three to four times as much as the cost of steam locomotives with their coal and water tender, coal and water depots, pumping plants, elevators, ash pits, trestle tracks, round house, and washing plant.

The cost of electrification for a particular situation requires a study of the features governing the length of road, density of traffic, number and weight of individual train units, ratio of average to maximum power, distribution of power, and the number and kind of substations.

The cost of electrification of steam railroads is being gradually reduced as the state of the art advances, as experimental work decreases, and as development charges are spread over larger amounts of equipment.

## COST OF ELECTRIFICATIONS COMPLETED OR PROPOSED.

The actual cost of electrifications completed is extremely hard to get. Railroads usually keep data on cost of construction behind "stone walls." Estimates are often required. A statistical study is, however, of value, and such data as are available are presented. The roads are:



### BOSTON & EASTERN RAILROAD, PROPOSED IN 1909.

| Item. | Amount. | Unit cost. | Total. | P. c. |
|---|---|---|---|---|
| Power station: | 8000 kw. | @ $100 | .......... | |
| Land, wharf, etc. | ............ | @ 4 | $32,000 | |
| Building, stack, intake | ............ | @ 20 | 160,000 | 35.0 |
| Boilers, engines, generators | ............ | @ 62 | 496,000 | |
| Other electrical equipment | ............ | @ 4 | 32,000 | |
| Miscellaneous | ............ | @ 10 | 80,000 | |
| Transmission line | 16 miles | @ 4,000 | 64,000 | |
| Third rail | 41.3 miles | @ 4,700 | 194,100 | |
| Track bonding | 41.3 miles | @ 500 | 20,650 | 28.0 |
| Transmission cable | 7 miles | @ 7,920 | 55,340 | |
| Terminal houses | 2 | @ 3,000 | 6,000 | |
| Converter substations, 3 | 10,000 kw. | @ 30 | 300,000 | |
| Cars, with 4–200-h. p. motors | 50 cars | @ 16,850 | 842,500 | 37.0 |
| Total | 41.3 miles. | @ 55,270 | $2,282,590 | 100.0 |

The road is now under construction between Boston and Beverly.

BOSTON AND ALBANY RAILROAD, BOSTON TERMINAL ZONE.

The estimates for electrification dated October 31, 1910, included 20.9 miles of four-track road, 9.89 miles of double-track road, and 25.0 miles of single track, and the electrification of all passenger tracks and some of the local freight sidings on the main line, to handle 3,619 daily train-miles. The estimates embraced the following:

| Item. | Amount. | Unit. | Total. | P. c. |
|---|---|---|---|---|
| Power station and three substations. | 22,500 kw. 11,350 kw. | $........ | $1,859,500 | 24.8 |
| Transmission lines | | | 446,500 | 20.1 |
| Third rail and bonding | 128 miles | @ 8,320 | 1,068,000 | |
| Electric locomotives | 16 | @ 34,650 | 554,400 | 31.2 |
| Motor cars | 62 | @ 17,829 | 1,105,400 | |
| Trail coaches | 31 | @ 10,851 | 336,500 | |
| Inspection shops | | | 350,000 | |
| Contingencies | | | 100,000 | 1.3 |
| Track and station changes | | | 940,000 | 13.3 |
| Tidal wave basins to protect third rail from water. | | | 60,000 | |
| Automatic block-signal, reconstruction. | | | 700,000 | 9.3 |
| | | | 7,520,300 | 100.0 |
| Less credit for: | | | | |
| Steam locomotives | 29 | 14,800 | 429,000 | ........ |
| Coaches | 113 | 6,000 | 678,000 | ........ |
| | | | 1,107,000 | |
| Total for 29 miles of route | 128 miles. | @ 50,000 | $6,413,300 | ........ |

The Boston and Albany is owned by the New York Central, which in its report to the Joint Board of Metropolitan Improvements advocated the use of the third-rail, 1200-volt, direct-current system for the Boston terminal electrification.

## NEW YORK, NEW HAVEN & HARTFORD RAILROAD. BOSTON TERMINAL ZONE.

The electrification costs dated November 15, 1910, were estimated as follows:

| Item. | Amount. | Unit. | Total. | P. c. |
|---|---|---|---|---|
| Power station.............. | 60,000 kw. | @ $100 | $6,000,000 | 18.3 |
| Transmission and overhead | 15.46 m. 4-track | @40,000 | .............. | ...... |
| single-phase contact lines. | 128.07 m. 2-track | @20,000 | .............. | ...... |
| | 32.44 m. 1-track | @ 7,000 | .............. | ...... |
| | 111.20 m. in yard | @ 4,000 | .............. | ...... |
| | 461.62 miles total. | @ 8,340 | 3,850,240 | 11.8 |
| Terminal, inspection, and repair shops. | .................... | ......... | 1,817,000 | 64.6 |
| Light passenger locomotives | 113 | @40,000 | 4,520,000 | |
| Heavy passenger locomotives | 49 | @45,000 | 2,205,000 | |
| Multiple-unit motor cars.... | 232 | @30,000 | 6,960,000 | |
| Multiple-unit trail cars ..... | 377 | @13,300 | 5,014,100 | |
| Spare parts for loco. and cars | .................... | ......... | 635,602 | |
| Automatic block signaling... | .................... | ......... | 1,750,000 | 5.3 |
| Total.................. | 461.62 miles | @70,950 | $32,751,942 | 100.0 |

*Note.*—The high cost of electrification seems to be caused by liberal estimates per unit, also by no credit for 101 steam locomotives and 227 passenger coaches replaced, and by the heavy peak load for 5 to 6 P. M. passenger trains. If the freight traffic had been added, the cost per ton-mile would have been radically decreased.

The total daily train mileage was estimated as 17,286 or 2.5 times that of the New York Central electric zone.

## NEW YORK CENTRAL, MOHAWK & MALONE DIVISION, ESTIMATE.

| Item. | Amount. | Unit. | Total. | P. c. |
|---|---|---|---|---|
| Power station............... | 12,390 kw. | @ $95.00 | $1,232,000 | 17.2 |
| Transmission and contact lines | ........... | ............. | 2,860,000 | 48.8 |
| Substations.................. | ........... | @ 17.50 | 630,000 | |
| Electric locomotives.......... | Thirty | @50,000.00 | 1,500,000 | 20.9 |
| Miscellaneous................ | ........... | ............. | 934,000 | 13.1 |
| Sum.................. | ........... | ............. | 7,156,000 | 100.0 |
| Less steam locomotives...... | ........... | ............. | 436,000 | ........ |
| Net total................ | 253 miles | @26,561.00 | $6,720,000 | ........ |

NEW YORK CENTRAL, CARTHAGE & ADIRONDACKS DIVISION, ESTIMATE.

| | | | | |
|---|---|---|---|---|
| Power station, steam | 1,230 kw. | @ $95.00 | $117,100 | 9.2 |
| Transmission and contact line | | | 690,000 | 62.2 |
| Substations, 16 | 3,000 kw. | @ 17.50 | 105,000 | |
| Electric locomotives | 4 | @ 50,000.00 | 200,000 | 15.6 |
| Miscellaneous | | | 166,900 | 13.0 |
| Sum | | | 1,279,000 | 100.0 |
| Less steam locomotives | 4 | @ 8,000.00 | 32,000 | ........ |
| Net total | 61 miles | @ 20,443.00 | $1,247,000 | ........ |

NEW YORK CENTRAL, NEW YORK & OTTAWA DIVISION, ESTIMATE.

| | | | | |
|---|---|---|---|---|
| Power station | 840 kw. | @ $95.00 | $80,000 | 6.5 |
| Transmission and contact line | | | 678,000 | 64.1 |
| Substations | | @ 17.50 | 105,000 | |
| Electric locomotives | 4 | @ 50,000.00 | 200,000 | 16.4 |
| Miscellaneous | | | 159,000 | 13.0 |
| Sum | | | 1,222,000 | 100.0 |
| Less steam locomotives | | | 26,000 | ........ |
| Net total | 60 miles | @ 19,934.00 | $1,196,000 | ........ |

NEW YORK CENTRAL, ADIRONDACK MOUNTAINS DIVISIONS.

| Item. | Amount. | Unit. | Total. | P. c. |
|---|---|---|---|---|
| Power station, steam | 15,000 kw. | @ $95.00 | $1,425,000 | 14.8 |
| Transmission and contact line | | | 4,228,000 | 52.5 |
| Substations | | @ 17.50 | 840,000 | |
| Electric locomotives | 38 | @ 50,000.00 | 1,900,000 | 19.7 |
| Sundry | | | 1,259,000 | 13.0 |
| Sum | | | 9,652,000 | 100.0 |
| Less steam locomotives | 42 | @ 11,762 | 494,000 | ........ |
| Net total | 374 miles | @ 24,486.00 | $9,158,000 | ........ |

Two 60,000-volt transmission circuits with (4 No. 0 wires) and one 11,000-volt contact line circuit.

"The enormous cost of electric equipment and the heavy increase in annual operating cost are due to the fact that the service proposed is totally unsuited for economical electric operation, long hauls, and infrequent heavy units being diametric-

ally opposite to that required for successful electrification." E. B. Katte, Chief Engineer of Electric Traction, New York Central Railroad, in a report of New York Public Service Commission, Second District, 1909.

The estimate is high, at $11,000 per mile for transmission and contact line; and for 38 electric locomotives to replace 42 steam locomotives.

## NEW YORK CENTRAL, HUDSON AND HARLEM DIVISIONS.

No data as yet available. See totals on page 542.

### NEW YORK, NEW HAVEN & HARTFORD.

The Electrification Costs on the New York Division to 1911 Approximated.

| Item. | Amount. | Unit. | Total. | Per cent. |
|---|---|---|---|---|
| Power station | 12,000 kw. | @ $100 | $1,200,000 | 24.0 |
| Overhead construction, 4- to 6-track bridges. | 22 miles | @37,000 | 814,000 | 16.3 |
| Feeders and track bonding | 88 miles | @ 342 | 30,000 | |
| Passenger locomotives | 41 | @45,000 | 1,845,000 | 41.5 |
| Freight locomotives | 2 | @75,000 | 150,000 | |
| Motor cars | 4 | @12,500 | 50,000 | |
| Signals, yards, sundry | | | 911,000 | 18.2 |
| Total for 22 miles of route. | 100 miles | @ $50,000 | $5,000,000 | 100.0 |

The estimate does not include the Harlem River-New Rochelle yards, 12.13 miles of 4- to 6-track road, the Stamford-New Canaan branch, the New York, West Chester & Boston, or the Stamford-New Haven extension.

### WEST JERSEY AND SEASHORE RAILROAD.

| Item. | Amount. | Unit. | Total. | P. c. |
|---|---|---|---|---|
| Power station: | | | | |
| Bldg., stack, coal handling | | | $354,900 | 25.2 |
| Equipment | 8,000 kw. | @ $80 | 640,000 | |
| Transmission line, 6 No. 1 | 70 m. | @ 3,455 | 241,500 | |
| Substation, buildings | 7 | | 72,000 | |
| Equipment | 17,000 kw. | @ 25 | 419,560 | 37.4 |
| Contact line: | | | | |
| Third rail, unprotected | 132 | @ 4,235 | 557,636 | |
| Trolley, temporarily | 20 | @ 4,120 | 80,500 | |
| Track bonding | | @ 648 | 102,659 | |
| Cars, wood, 47 tons, 480 h.p., 1906. | 93 | @12,214 | 1,135,900 | |
| Cars, steel, 52 tons, 480 h.p., 1906. | 15 | @19,500 | 292,500 | 37.4 |
| Car repair and in sheds | | | 46,674 | |
| Total. | 150 miles. | 26,300 | $3,943,829 | 1000 |

### BALTIMORE & ANNAPOLIS SHORT LINE. ESTIMATE.

| Item. | Amount. | Unit. | Total. D. c. | Total. A. c. | Per cent. D. c. | Per cent. A. c. |
|---|---|---|---|---|---|---|
| Power station | | | $21,000 | $62,000 | 5.2 | 18.0 |
| Transmission line and poles, for d. c. (6 No. 2 wires). | | | 65,000 | 36,000 | ...... | ...... |
| Substation buildings | | | 15,000 | 3,000 | | |
| Substation with converters | | @17.50 kw. | 39,000 | ........ | | |
| Substation with transformers | | | | 8,000 | | |
| Bonding | | | 18,000 | 11,000 | 67.8 | 38.6 |
| Third rail | 33 miles | @$4000 | 132,000 | ........ | | |
| Catenary trolley, poles, and wire | 33 miles | @ 2273 | ........ | 75,000 | | |
| Nine cars completely equipped | | | 107,300 | 149,300 | 27.0 | 43.4 |
| Total with direct current | 33 miles | @12,040 | $397,300 | ........ | 100 | ...... |
| Total with alternating current | 33 miles | @10,440 | ....... | $344,300 | ...... | 100.0 |

### GRAND TRUNK RAILWAY—ST. CLAIR TUNNEL. ESTIMATED.

| Item. | Amount. | Unit. | Total. | P. c. |
|---|---|---|---|---|
| Power station | 2500 kw. | @ $100 | $250,000 | 50. |
| Contact line | 12 miles | @ 5,000 | 60,000 | 12. |
| Locomotive 66-ton | 6 units | @ 26,500 | 159,000 | 32. |
| Sundry | | | 31,000 | 6. |
| Total | 12 miles | $41,666 | $500,000 | 100 |

The transmission line is short. Single track is used except at terminals, where tracks are 4 to 10 deep.

### OHIO AND INDIANA INTERURBAN RAILWAYS.

About 5000 miles of track have been built in these two states. Gross earnings are 29.5 cents and operating expenses 15.8 cents per car-mile.

Cost of roadbed was $16,000; power plants, $2,200; transmission lines and substations, $3,000; trolley line, $1,600; cars $1,200; general expenses, $1,000; total $25,000, per mile. Electrification cost was thus: Power station, 24.4 per cent.; transmission lines and substations, 33.3 per cent.; trolley line, 17.9 per cent.; cars, 13.3 per cent.; and sundry, 11.1 per cent. This average, from 20 typical roads, was obtained in 1909. *Darlington.*

GREAT NORTHERN RAILWAY, CASCADE TUNNEL. ESTIMATE.

| Item. | Amount. | Unit. | Total. | P. c. |
|---|---|---|---|---|
| Hydro-electric power plant | 7500 kw. | @ $160 | $1,200,000 | 74 |
| Transmission line, six No. 0 wires, 33,000-volt. | 30 miles | @ 2,000 | 60,000 | 6 |
| Overhead line material, O. B. Co. | 6 miles | @ 2,000 | 12,000 | |
| Overhead line, balance of material and erection. | 6 miles | @ 3,500 | 21,000 | |
| Locomotives, 1900-h. p. each | 4 units | @ 40,000 | 160,000 | 10 |
| Sundry items | .......... | .......... | 167,000 | 10 |
| Total, estimate | 6 miles | @ $270,000 | $1,620,000 | 100 |

This makes a large total per mile. If the electric zone is extended, the investment per mile will be decidedly smaller.

SPOKANE & INLAND EMPIRE RAILROAD. ESTIMATES.

| Cost of electrification compared. | Direct current. | Alternating current. |
|---|---|---|
| Power plant, 6000 kilowatts | .................. | .................. |
| Transmission lines (60,000-volt) | $122,640 | $140,000 |
| Feeders | 474,600 | 19,800 |
| Bonding of rails | 40,150 | 40,150 |
| Trolley line (two No. 0000 conductors) | 343,100 | .............. |
| Trolley line (catenary construction) | .................. | 306,600 |
| Transformer substations | .................. | 156,988 |
| Frequency changing stations | .................. | 106,400 |
| Rotary converter substations | 338,548 | ................ |
| Electrical equipment of rolling stock | 259,600 | 286,250 |
| Total for 162 miles of track | $1,578,638 | $1,056,188 |
| Saving of single-phase over direct-current | .................. | $522,450 |

Electrification plans were based on 146 miles of main line, or 162 miles of track, and the use of either the 3-phase, 60-cycle, direct-current, 600-volt rotary converter system; or the 3-phase, 60-cycle, motor-generator, single-phase, 25-cycle, 6600-volt system.

Power at 60 cycles was available at an electric lighting plant but required that four 1000-kilowatt frequency changers be used, consisting of 3-phase, 60-cycle, 4000-volt induction motors coupled to 25-cycle, revolving field, single-phase generators. Storage batteries were also added to minimize the railway load peaks.

If the frequency changing station had not been used an additional $106,400 would have been saved. Changes were made after the contract for the equipment was closed, and it is now considered that the saving effected by the single-phase system was in the immediate neighborhood of $800,000. The generation of energy at 25 cycles at a new water power plant will decrease the unit cost of electrification.

SOUTHERN PACIFIC COMPANY, ALAMEDA, CALIFORNIA: 1910.

| | | | |
|---|---|---|---|
| 12–645-h. p. Parker boilers | @ | $17 | $131,580 |
| 2–5000-kw. Westinghouse turbo-generators | @ | 38 | 380,000 |
| 2 surface condensers | @ | 23,000 | 46,000 |
| 44 multiple-unit cars, with 4–125-h.p. motors | @ | 8500 | $374,000 |
| 6–750 kw., 600-volt, rotary counters | @ | .... | ........ |

The work will not be completed until late in 1911.

PARIS-ORLEANS RAILWAY: 1904.

| Item. | Amount. | Unit. | Total. | P. c. |
|---|---|---|---|---|
| Power station | 2000 kw. | @$206 | $412,000 | 27.6 |
| Transmission lines | 21.18 miles. | @4900 | 104,000 | |
| Transformer-converter substations | 3 | ........ | 215,000 | 52.5 |
| Contact line | 37.29 miles. | @12400 | 463,000 | |
| Electric locomotives | 11 | | 280,000 | 19.2 |
| Motor cars | 5 | | | |
| Miscellaneous | | | 16,000 | |
| Total | 37.29 miles. | @40,000 | $1,490,000 | 100.0 |

PARIS-METROPOLITAN RAILWAY: 1904.

| | | |
|---|---|---|
| Power stations, three | 2,405,800 | 46.0 |
| Track equipment | 218,800 | |
| Substations, four | 505,800 | 19.0 |
| Transmission line | 276,000 | |
| Rolling stock | 1,693,200 | 35.0 |
| Miscellaneous | 150,400 | |
| Total for 15.42 miles of track...@340,000 | $5,250,000 | 100.0 |

Note the high cost of power stations. Data of 1904 are not valuable.

**GERMAN STATE RAILWAYS.**

German engineers have been actively engaged in the study of electric power for the Prussian State Railroad, which includes 21,016 miles of single track.

The present electrification plans embrace the following:

Central power plants, 125 miles apart, interconnected to allow a mutual rendering of assistance in case one is disabled.

Transmission line voltage, 50,000; transformers, at intervals of 25 miles along the line, 3000 kilowatt for single track and 5000 kilowatt for double track. Contact line voltage, 10,000.

Power required for trains, per mile of double track, 200 kilowatt.

Power required for trains, per mile of single track, 120 kilowatt.

Electric locomotives to aggregate 64 per cent. of the number, and to have 73.8 per cent. of the empty weight, of steam locomotives. Number of electric locomotives required, 955 at $16,000 each; or $.1834 per pound. Steam locomotives now cost $.1186 per pound.

| Estimates on cost. | Per mile single track. | Per mile. double track. | Electrification. Total cost. | Per cent. |
|---|---|---|---|---|
| No power plant. Would cost. . | . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | | | 20 |
| Transmission line. . . . . . . . . . . . | $1530 | $2490 | $42,500,000 | |
| Transformer equipment. . . . . . . | 862 | 1436 | 25,000,000 | 50 |
| Contact line, 21,016 miles. . . . . | 3830 | . . . . . . . . . . . . | 167,500,000 | |
| Locomotives and motor cars. . | 7358 | . . . . . . . . . . . . | 152,500,000 | 30 |

Estimates by Pb. Pforr. See. U. S. Consular Report, No. 3411, 1909.

ESTIMATE ON COST OF OPERATION OF GERMAN RAILROADS.

| Items. | Proposed electric service. | Present steam. service. |
|---|---|---|
| Steam power 3,481,000,000 kw-hr., @ .833 . . . . . . . . . (including fixed charge on investment). | $29,000,000 | $26,000,000 |
| Depot service oil and waste, and miscellaneous. . . . . . . . . | 8,648,000 | 13,398,000 |
| Minor accounts, loss by fire in forests. . . . . . . . . . . . . . . . . | 0 | 1,750,000 |
| Enginemen and firemen on trains. . . . . . . . . . . . . . . . . . . . . | 10,950,000 | 15,950,000 |
| Maintenance of rolling stock. . . . . . . . . . . . . . . . . . . . . . . . | 8,500,000 | 10,500,000 |
| Added interest, $235,000,000 @ 5 per cent. . . . . . . . . . . . . . | 11,750,000 | . . . . . . . . . . . |
| Maintenance of lines @ 2 per cent. . . . . . . . . . . . . . . . . . . . . | 4,250,000 | . . . . . . . . . . . |
| Maintenance of transformers @ 5 per cent. . . . . . . . . . . . . . . | 1,250,000 | . . . . . . . . . . . |
| Maintenance of water and coal stations. . . . . . . . . . . . . . . . | 0 | 1,250,000 |

The saving in coal alone is estimated at $4,750,000 per annum.

The saving in the future in the cost of double tracking and by the use of water power will increase the advantage of electric traction.

## BURGDORF-THUN RAILWAY: 1899.

### INTERURBAN RAILWAY.

| Items. | Amount. | Unit. | Total. | Per cent. |
|---|---|---|---|---|
| Power plant, estimate | 4,500 kw. | ......... | $450,000 | 72.8 |
| Transmission line, 15,500-volt, 3-phase | 24 miles. | ......... | 26,600 | 19.9 |
| Transformers, 14 substations | 450 kw. | @ $5 | 30,400 | |
| Contact line, 2-wire, 3-phase, 750-volt. | 8-mm. | ......... | 66,500 | |
| Motor cars, six 32-ton | 320-h. p. | ......... | 44,650 | 7.3 |
| Locomotives, two 33-ton | 300-h. p. | | | |
| Total | 29 miles | @ 21,300 | $618,150 | 100.0 |

## VALTELLINA RAILWAY: 1902.

| Items. | Amount. | Unit. | Total. | Per cent. |
|---|---|---|---|---|
| Power plant | 7500-h. p. | ........ | $500,000 | 51.6 |
| Power plant machinery | | | 140,000 | |
| Line construction | | | 340,000 | 27.4 |
| Rolling stock | | | 260,000 | 21.0 |
| Total | 67 miles | @ $18,500 | $1,240,000 | 100.0 |

## MILAN-VARESE RAILWAY: 1902.

| Items. | Amount. | Unit. | Total. | Per cent. |
|---|---|---|---|---|
| Power plant with storage batteries | | | $240,000 | 21.8 |
| Third rail, etc | 1 | ........ | 460,000 | 41.9 |
| Motor cars | 25 | ........ | 340,000 | 36.3 |
| Locomotives | 5 | @ $12,000 | 60,000 | |
| Total | 105.7 miles | @ $10,400 | $1,100,000 | 100.0 |

Data for 1902 are not very valuable.

COST OF ELECTRIFICATION, SUMMARY.

| Name of railroad. | Electric mileage. | Estimated cost of electrification. | Cost per single-track mile. | Notes on construction. |
|---|---|---|---|---|
| Boston & Eastern | 41 | $2,282,590 | $55,270 | Proposed 600-volt system. |
| Boston & Albany | 128 | 6,413,000 | 50,000 | Proposed 1200-volt system. |
| Boston & Maine | 22 | 880,000 | 44,000 | Hoosac Tunnel section. |
| New York, New Haven & H. | 461 | 32,750,000 | 70,950 | Proposed Boston Terminal. |
| New York, New Haven & H. to 1911 | 100 | 5,000,000 | 50,000 | Woodlawn-Stamford, Connecticut. |
| N. Y., Westchester & Boston. | 63 | 5,000,000 | .......... | New York to White Plains, etc. |
| New York Central | 125 | 10,700,000 | 85,600 | N. Y. City to North White Plains. N. Y. City to Yonkers. |
| New York Central | 374 | 9,158,000 | 24,486 | Adirondack Division, estimate. |
| Manhattan Elevated | 118 | 17,000,000 | 144,000 | Elevated R. R. |
| Long Island | 120 | 11,000,000 | 91,667 | Brooklyn-Long Island. |
| Pennsylvania | 50 | 20,000,000 | 400,000 | Newark, New York, Long Island. |
| West Jersey & Seashore | 150 | 3,943,829 | 29,300 | Philadelphia-Atlantic City. |
| Annapolis Short Line | 33 | 344,300 | 10,433 | Baltimore-Annapolis. |
| Grand Trunk | 12 | 500,000 | 41,666 | Port Huron-Sarnia Tunnel. |
| Michigan Central | 19 | 950,000 | 50,000 | Detroit-Windsor Tunnel. |
| Ohio & Indiana interurbans | 5000 | ........... | 9,000 | Average of 20 roads. |
| Spokane & Inland | 162 | 1,056,188 | 6,520 | Without power plant. |
| Great Northern | 6 | 1,200,000 | 200,000 | Cascade Tunnel. |
| Southern Pacific | ........ | 10,000,000 | .......... | Oakland suburban service. |
| Swedish State | ........ | 4,000,000 | .......... | To be completed in 1914. |
| Paris-Orleans | 37 | 1,490,000 | 40,000 | Completed in 1904. |
| Paris-Metropolitan | 15 | 5,250,000 | 340,400 | Completed in 1904. |
| German State | ........ | ........... | 7,000 | Without power plant. |
| Burgdorf-Thun, interurban | 29 | 618,150 | 21,300 | Year 1899. Three phase. |
| Valtellina | 67 | 1,240,000 | 18,500 | Year 1902. Three phase. |
| Milan-Varese | 105 | 1,100,000 | 10,400 | Year 1899. Third rail. |

Data are incomplete and approximate. Short lines are hardly comparable with long lines, because local or short-haul service requires heavy investment per mile. In some cases, *e. g.*, Pennsylvania Railroad, all of the tunnel roads, terminal railways, suburban development, etc., a large investment has been made and the full use of same will not be obtained until extensions are completed. In two cases noted, power is purchased, and 30 per cent. of the usual investment was not made. Cost of cars which, in reality, should not be charged against the cost of electrification, and cost of track and terminal changes or improvements have been included in the cost of electrification. Other data can be tabulated on the cost per ton-mile hauled.

## ERRORS TO BE AVOIDED.

Errors to be avoided in electrification are noted briefly as follows:

**Electrification should not be compulsory** at the present time. Railroads should be given time to make an honest study of the application of electric motive power, as used on similar or longer roads.

**Power plant load factor** must not be low. This was considered in detail in Chapter XII, which see.

**Electrification for short distances** should be avoided. Electrification

for distances less than twelve miles cannot, from the very nature of the problem, produce economical results and a profitable financial investment for the railroad. This has been outlined and emphasized thruout this chapter and also in the chapter on Power Plants, under load factor.

**Freight haulage** should not be neglected. Net earnings from freight are large and persistent, and freight haulage by electric locomotives deserves consideration in every plan for electrification. The power station, if provided for passenger requirements only, will have a large unused capacity between the hours of peak load, which could be utilized for the transportation of freight. The occupation and use of the tracks and electric contact line by passenger trains, during these hours of peak load, prevent the operation of freight trains at such times; while at other hours the freight traffic automatically fills in the load valleys. Thus the investment is utilized to best advantage, *i. e.*, continually, and apparatus is worked at near the full load.

**Amount of equipment** planned or purchased for the electric power plant, lines, substation, and motive power should not be too small for the maximum service, the holiday and snow storm conditions. Some rolling stock will always be undergoing repairs. Energy is required for lighting, heating, shops, power, signals, and transmission losses. Power plants should be so constructed that there is an opportunity to expand symmetrically and economically, and without that waste which follows an unsatisfactory compromise. Rebuilding is expensive, and plans should be so comprehensive that radical changes will occur at long intervals.

**Number of power plants and substations** should not be too large. Ordinarily substations are too near together. This was formerly necessary, to decrease the losses in low-voltage feeder lines. The first result of such a mistake is to increase the cost of buildings and substation attendants; and the load factor of each substation, and of its feeding lines, becomes notoriously bad. On an ordinary railroad with 75 miles of route and about 16 trains each way per day, electrification plans for which have been developed by the writer, a total maximum output of about 8,000 kilowatts was required. One substation, or the main station, at the middle of the line, carrying the full load, would have a load factor of 64 per cent.; 2 substations, a load factor of 35 and 41 per cent.; and 3 substations, 18 to 20 miles apart, a load factor of about 31 per cent. Amount of equipment required to deliver the average kilowatts, or to haul the ton-mileage, increases rapidly as the number of substations is increased. This apparently leads to an argument for the single-phase system, because the high voltage used on the contact line allows transformer substations to be placed long distances apart; and the load is so equalized that there is the minimum equipment for the maximum work. The cost of electrification and operation of long railroads would be ex-

cessive with frequent substations, 1200-volt, direct-current, rotating apparatus, and substation attendants.

Power plants must be used jointly by railroads, whenever it is possible, to avoid duplication in investment and to obtain higher load factors and economy of operation.

"**The simultaneous maintenance of the facilities and working forces for both steam and electric service** within the same limits will be rarely profitable for the reason that a large proportion of expenses incident to both kinds of service is retained, without realizing the full economy of either. To secure the fullest economy, it is necessary to extend the electric service over the whole length of the existing engine stage or district, and to include both passenger and freight trains." E. H. McHenry, Vice-President, New York, New Haven & Hartford Railroad.

One great obstacle to electrification is the large capital required. The railroad must not pay interest upon a double investment, that for steam and that for electricity. Terminal electrification is expensive and no gain is made when one end of a railroad is electrified while the rest is operated by steam. It is certainly a case of steam plus electricity, which obviously is an uneconomical procedure. The substitution should in all cases include passenger and freight operation and yard switching. Partial electrification will always be financially unsuccessful.

**Steam railroad electrification should not be started until there is a proper appreciation of the problems involved.** A railroad requires more consideration than an interurban road, and experience in the latter does not qualify one for work on the former. Where the traffic is important, experiments must not be tried. Without proper appreciation of the problem, reliable and economical service which is needed for freight and passenger work, damage will result. Enthusiasm cannot be used as a basis for procedure. Facts must not be concealed, for they may react to the detriment of those responsible for good operating results, and often to the embarrassment of the railroad.

### ELECTRICAL ENGINEERS OF RAILROADS.

The electric railway engineer's work in the electrification of railroads requires preparation. This should enable him, first of all, to comprehend the scope of specific railroad problems. For their solution, the real facts must be obtained and so fortified with general and detailed information that they cannot be set aside or questioned. The ability to refer to authorities, to the recorded experience of others, to collect the data and facts, and to do it quickly when needed, certainly constitutes a valuable asset in this engineering work. The engineer's note book or record of experience is generally very valuable.

The men who have been graduated from a course of study embracing

electric railway engineering, and who will follow electrification work, need long experience in practical work, in power-plant operation, construction of transmission and contact lines, repair shop experience, and an apprentice course; to be followed by design of apparatus, and study of cost of equipment, and cost of operation. A study of statistical tables and the equipment and methods used on different railways is most advantageous. In electrification work, economical and efficient *methods* are of paramount importance.

The electrical superintendent of a road often has charge of the locomotives and electrical equipment used on the division. He reports to the superintendent and engineer of maintenance of way, on the traffic and construction matters respectively; and to the mechanical superintendent on those things relating to the mechanical details of the locomotive construction and maintenance in operation. The electrical superintendent often has under him a road foreman of electric engines and motor cars, and the chief engineer of the power house.

"The duties of the electrical engineer are to specify the electrical apparatus needed to satisfy the load or working conditions; to fit this apparatus in with the present motive power; to act as interpreter between the railroad and the manufacturer; to so arrange that the number of standards used is not unnecessarily increased; further, to secure the co-operation of the different departments of the transportation system and to make certain that the new equipment will be properly used and cared for." W. N. Smith, to A. I. E. E., Dec., 1907.

"The question of electrification of trunk lines devolves upon the engineers of our railways to determine to what extent electric power is justifiable in heavy trunk-line service. It is a problem of great magnitude and involves not only technical skill, but judgment of the highest order, and the solution must, in the final analysis, be made by railway men, familiar with the intricacies of railway operation and its needs. Railway engineers should prepare for this economic change that has already begun, in order that the problems that demand solution may be solved on a sound basis, and that costly mistakes which ignorance would otherwise impose may be avoided." L. C. Fritch, President of the American Railway Engineering Association, referring to the Pennsylvania Railroad electrification at New York City, March, 1911.

ENGINEERS FOR ELECTRIC RAILROADS.

| Name of railroad. | Name of engineer. | Title. | Address. |
|---|---|---|---|
| Boston Elevated | Paul Winsor | Chief Engineer of M. P. | Boston. |
| | John W. Corning | Electrical Engineer | Boston. |
| New York Central | J. F. Deems | General Supt. of M. P. | New York. |
| | E. B. Katte | Chief Engineer of E. T. | New York. |
| | H. A. Currie | Ass't Electrical Engineer | New York. |
| | W. A. Del Mar | Ass't Engineer of Electrical Transmission Dep't. | New York. |
| | Wm. G. Carleton | Supt. Power, Electrical Division. | New York. |
| | A. W. Whaley | General Superintendent of Electrical Division. | New York. |

ENGINEERS FOR ELECTRIC RAILROADS. (Continued.)

| Name of railroad. | Name of engineer. | Title. | Address. |
|---|---|---|---|
| New York, New Haven & Hartford. | E. H. McHenry | Vice President | New Haven. |
| | W. S. Murray | Electrical Engineer | New Haven. |
| | C. L. Peterson | Engineer of Power Plant | Cos Cob. |
| | H. S. Day | Foreman of Shops | Stamford. |
| | H. Gilliam | Electrical Superintendent | Stamford. |
| | W. J. O'Meara | Foreman of Electric Locos. | New York. |
| | L. S. Boggs | Supt. Overhead Construct. | New Rochelle. |
| Boston & Maine | L. C. Winship | Electrical Superintendent | Hoosac Tunnel. |
| Long Island | Geo. Gibbs | Chief Engineer of E. T. | New York. |
| | L. S. Wells | Electrical Superintendent | Long Island. |
| | L. S. Woodruf | Assistant Superintendent | Long Island. |
| | R. W. Brodmann | Foreman of Shops | Morris Park. |
| | F. G. Clark | Superintendent of Power | Long Island. |
| Pennsylvania: | George Gibbs | Chief Engineer of E. T. | New York. |
| New York Terminal Div. | E. R. Hill | Assistant to Chief Engr. | New York. |
| | Hugh Pattison | Supt. of Construction | New York. |
| | R. D. Combs | Structural Engr. of E. T. | New York. |
| West Jersey & Seashore | J. W. Rogers | Electrical Supervisor | Camden, Pa. |
| | B. F. Wood | Assistant Engineer | Altoona, Pa. |
| | J. R. Sloan | Electrical Engineer | Altoona, Pa. |
| Interborough Rapid Transit | Henry G. Stott | Superintendent of M. P. | New York. |
| | J. S. Doyle | Supt. of Equipment | New York. |
| | L. B. Stillwell | Electrical Director | New York. |
| Hudson & Manhattan | Hugh Hazelton | Electrical Engineer | New York. |
| | L. G. Smith | Chief Electrician | New York. |
| Baltimore & Ohio | J. H. Davis | Electrical Engineer | Baltimore. |
| | L. S. Billau | Asst. Elec. Engineer | Baltimore. |
| Boston & Maine | W. S. Murray | Electrical Engineer | New Haven. |
| Canadian Pacific | H. H. Vaughan | Assistant to V. P | Montreal. |
| | N. Cauchon | Consulting Engineer | Ottawa. |
| Delaware, Lackawanna & Western. | T. E. Clark | General Superintendent | Scranton, Pa. |
| | T. S. Lloyd | Superintendent M. P. | Scranton, Pa. |
| | H. M. Warren | Electrical Engineer | Scranton, Pa. |
| Delaware & Hudson | C. S. Sims | V. P. and G. M. | Albany. |
| | Axel Ekstrom | Electrical Engineer | Albany. |
| Erie R. R. | W. J. Harahan | V. P. of Engineering Dept. | New York. |
| | D. H. Wilson, Jr. | Electrical Engineer | Meadville, Pa. |
| | R. C. Thurston | Supt. Electrical Service | Avon, N. Y. |
| Grand Trunk | W. D. Hall | Supt. of Motive Power | Port Huron. |
| | J. F. Jones | Supt. of Terminals | Port Huron. |
| Michigan Central | J. C. Mock | Electrical Engineer | Detroit. |
| | H. B. P. Wrenn | Electric Locomotive Engr. | Detroit. |
| Lackawanna & Wyoming Val. | J. H. Murray | Supt. of Transmission | Scranton. |
| Chicago Terminal Commission | H. G. Burt | Chief Engineer | Chicago. |
| | George Gibbs | Consulting Engineer | New York |
| Aurora, Elgin & Chicago | E. F. Gould | Electrical Engineer | Wheaton, Ill. |
| Ft. Dodge, Des Moines & S. | H. A. Fiske | Electrical Engineer | Boone, Iowa. |
| Wabash | A. O. Cunningham | Chief Engineer | St. Louis. |
| Northern Pacific | W. J. Bohan | Electrical Engineer | St. Paul. |
| Great Northern | R. D. Hawkins | Supt. of Motive Power | New York. |
| Spokane & Inland Empire | A. M. Lupfer | Chief Engineer | Spokane. |
| | J. B. Ingersoll | Chief Electrical Engineer | Spokane. |
| Northwestern Pacific | F. T. Vanatta | Chief Electrician | Sausalito. |
| Pacific Electric | S. H. Anderson | Electrical Engineer | Los Angeles. |
| Southern Pacific Company | Allen H. Babcock | Electrical Engineer | San Francisco. |
| Northern Electric, Cal. | J. P. Edwards | Electrical Engineer | Chico, Cal. |

## ENGINEERS FOR ELECTRIC RAILROADS. (Continued.)

| Name of railroad. | Name of engineer. | Title. | Address. |
|---|---|---|---|
| London Electric | J. R. Chapman | Chief Engineer | London. |
| | A. R. Cooper | Electrical Engineer | London. |
| Mersey Ry | J. Shaw | Electrical Engineer | Liverpool. |
| Lancashire & Yorkshire | J. A. F. Aspinwall | General Manager | Liverpool. |
| North-Eastern, England | C. H. Merz | Consulting Engineer | New Castle. |
| Midland Ry., England | J. Dalziel | Ass't. Loco. Supt | Lancaster. |
| | J. Sayers | Electrical Engineer | |
| London, Brighton & S. C | Wm. Forbes | General Manager | London. |
| | Philip Dawson | Electrical Advisor | London. |
| Swedish State | Robt. Dahlander | Chief Engineer | Stockholm. |
| Paris-Orleans | Paul du Bois | Engineer | Paris. |
| Paris-Lyons-Mediterranean | M. Auvert | Engineer | Paris. |
| Western French | M. Mazen | Engineer | Paris. |
| Southern French | M. Jullian | Engineer | |
| Prussian State | G. O. Wittfeld | Electrical Advisor | |
| Austrian State | M. Krasny | Engineer | |
| Swiss Federal | W. Wyssling | Secretary | |
| Bernese Alps | Charles Wirth | Engineer | Berne. |
| | L. Thorman | Consulting Engineer | Berne. |
| Italian State | M. Verola | Chief Engineer, Elec. Dept. | |

## AMERICAN RAILWAY ENGINEERING ASSOCIATION, COMMITTEE ON ELECTRIC WORKING.

| Name of engineer. | Name of railroad. | Address. |
|---|---|---|
| George Gibbs | Pennsylvania | New York |
| E. H. McHenry | New York, New Haven & H. | New Haven |
| G. W. Kittridge | New York Central | New York. |
| G. A. Harwood | | New York. |
| C. E. Linsay | | New York. |
| E. B. Katte | | New York. |
| J. B. Austin, Jr. | Long Island | Long Island City. |
| J. A. Savage | | Long Island City. |
| A. O. Cunningham | Wabash | St. Louis. |
| L. C. Fritch | Chicago Great Western | Chicago. |
| N. E. Baker | Illinois Central | Chicago. |

## AMERICAN RAILWAY ASSOCIATION, COMMITTEE ON HEAVY ELECTRIC TRACTION.

| Name of engieer. | Name of railroad. | Address. |
|---|---|---|
| W. S. Murray | New York, New Haven & H | New York. |
| E. B. Katte | New York Central | New York. |
| E. R. Hill | Pennsylvania | New York. |
| J. H. Davis | Baltimore & Ohio | Baltimore. |
| Hugh Hazelton | Hudson & Manhattan | New York. |
| E. F. Gould | Aurora, Elgin & Chicago | Wheaton, Ill. |

## MANUFACTURING AND CONSTRUCTING CORPORATIONS.

| Name of company. | Name of engineer. | Title. | Address. |
|---|---|---|---|
| General Electric | E. B. Rice, Jr. | V. P. and Chief Engineer. | Schenectady. |
| | J. G. Barry | Manager Ry. Department | Schenectady. |
| | W. B. Potter | Ch. Engr. Ry. Department | Schenectady. |
| | A. H. Armstrong | Ass't Engr. Ry. Dept. | Schenectady. |
| | S. T. Dodd | Ry. Engrng. Department. | Schenectady. |
| | A. F. Batchelder | Locomotive Department. | Schenectady. |
| | W. J. Clark | Mgr. Traction Dept. | New York. |
| Westinghouse | B. G. Lamme | Electric Engineer | Pittsburg. |
| | N. W. Storer | Engineer Ry. Division | Pittsburg. |
| | C. S. Cook | Mgr. Ry. Department | Pittsburg. |
| | F. E. Wynne | Engr. Ry. Project Dept. | Pittsburg. |
| | F. Darlington | Sales Engineer | Pittsburg. |
| | Robt. L. Wilson | Supt. Loco. Installations | Pittsburg. |
| | F. H. Shepard | Special Representative | New York. |
| Allis-Chalmers | L. E. Bogen | Electrical Estimator | Milwaukee. |
| Siemens & Halske | | | Berlin. |
| Allgemeine Elektricitäts | | | Berlin. |
| Bergmann Electric | | | Berlin. |
| Ganz Electric | | | Budapest. |
| Oerlikon | | | Zurich, Sweiz. |
| Brown, Boveri | | | Baden, Sweiz. |
| Alioth Electric | | | Basle, Sweiz. |
| Italian Westinghouse | | | Vado-Ligure. |
| Thury | | | Geneva. |

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## CHAPTER XV.

## WORK DONE IN RAILROAD ELECTRIFICATION

**Outline.**

**General Status.**
**Classification of Development.**
**Railroads Operating Divisions by Electricity. List.**
**Train Service of Electric Railroads. List.**
**Technical Data on Completed Electrifications:**

Boston & Maine R. R.; New York, New Haven & Hartford R. R., New York Division; New York Central & Hudson River R. R., Harlem & Hudson Divisions, West Shore Railroad; Pennsylvania Railroad, Long Island Railroad, Pennsylvania Tunnel & Terminal R. R., West Jersey & Seashore R. R.; Hudson & Manhattan R. R.; Baltimore & Annapolis Short Line; Baltimore & Ohio R.R; Michigan Central R.R; Grand Trunk R.R; Erie R.R; Chicago, Burlington & Quincy, Colorado & Southern R. R., Denver & Interurban R. R.; Spokane & Inland Empire R. R.; Great Northern Ry.; Southern Pacific Company.

**Terminal Railway and Switch Yard Electrification** (see Chapter I.)
**Proposed Electrifications:**

Boston & Albany R. R.; Delaware, Lackawanna & Western R. R.; Illinois Central R. R; Canadian Pacific Railway; Butte, Anaconda & Pacific Railway; other proposed American Railroad Electrifications.

**European Railroad Electrification:**

England, Sweden and Norway, Spain and France, Germany and Austria, Switzerland and Italy.

**Conclusion and Summary.**

## CHAPTER XV.

# WORK DONE IN RAILROAD ELECTRIFICATION.

### GENERAL STATUS.

The general status of electric traction for railway trains is obtained from technical facts on the *extent* and *character* of the constructions which have been completed. The extent of the progress has been shown by the number of motor cars and locomotives in use, and the electric mileage. The character of the construction has been set forth in the technical descriptions of rolling equipment, transmission and contact lines, and power plants. Electric traction has been adopted, or is being considered, by progressive railroads, which are able to do things on a large scale; second-class, weak roads have not adopted electric train haulage.

Classification of the development under service, traffic, location, and equipment is first illustrated.

CLASSIFICATION OF ELECTRIC RAILWAY DEVELOPMENT.

| Class of railway service. | Kind of service. Pass. | Kind of service. Fgt. | Cars in trains. | Right-of-way. | Owns terminals. | MCB couplers. | Best examples of a railway of this class. | Year equipped. |
|---|---|---|---|---|---|---|---|---|
| Railroad | Yes. | Yes. | All. | All. | Yes. | ...... | Lancashire & Yorkshire | 1903 |
| | Yes. | Part. | All. | All. | Yes. | Yes. | New Haven, New York Div. | 1907 |
| | Yes. | No. | All. | All. | Yes. | Yes. | Long Island Railroad | 1904 |
| Terminal | Yes. | No. | All. | All. | Yes. | Yes. | New York Central | 1906 |
| | Yes. | No. | All. | All. | Yes. | Yes. | Pennsylvania R. R. | 1910 |
| Freight | Yes. | Yes. | All. | All. | Yes. | Yes. | Pacific Electric Ry | 1898 |
| | Yes. | Yes. | All. | All. | Yes. | Yes. | New Haven, Harlem Division | 1911 |
| Switch | No. | Yes. | All. | All. | Yes. | Yes. | Hoboken Shore R. R. | 1898 |
| | No. | Yes. | All. | All. | Yes. | Yes. | Bush Terminal R. R. | 1904 |
| Tunnel | Yes. | Yes. | All. | All. | Yes. | Yes. | Baltimore & Ohio | 1895 |
| | Yes. | Yes. | All. | All. | Yes. | Yes. | Grand Trunk | 1907 |
| | Yes. | Yes. | All. | All. | Yes. | Yes. | Great Northern | 1909 |
| Mountain | No. | Yes. | All. | All. | Yes. | ...... | Giovi Ry., Italy | 1909 |
| Parallel | Yes. | No. | All. | All. | Yes. | Yes. | West Jersey and Seashore | 1907 |
| | Yes. | No. | Few. | All. | No. | Yes. | West Shore R. R. | 1906 |
| Branch | Yes. | No. | All. | All. | Yes. | Yes. | Erie R. R. | 1907 |
| Rapid transit | Yes. | No. | All. | All. | Yes. | No. | Interborough Rapid Transit | 1904 |
| | Yes. | No. | All. | All. | Yes. | Yes. | Hudson & Manhattan | 1908 |
| | Yes. | No. | All. | Part. | Part. | No. | Aurora, Elgin & Chicago | 1902 |
| Elevated | Yes. | No. | All. | All. | Yes. | No. | Manhattan Elevated R. R. | 1902 |
| Suburban | Yes. | No. | All. | Yes. | Yes. | Yes. | London, Brighton & South C. | 1910 |
| Interurban | Yes. | Yes. | All. | All. | Yes. | Yes. | Los Angeles Pacific | 1900 |
| | Yes. | Yes. | All. | All. | Yes. | Yes. | Spokane & Inland Empire | 1906 |
| | Yes. | Light. | Few. | Part. | No. | No. | Chicago & Milwaukee Electric | 1899 |
| | Yes. | Light. | Few. | All. | No. | No. | Chicago, Lake Shore & South B. | 1908 |
| | Yes. | Yes. | Frt. | Part. | Yes. | Frt. | Illinois Traction Company | 1903 |
| | Yes. | Yes. | Frt. | Part. | Yes. | Frt. | Waterloo, Cedar Falls & North. | 1900 |
| Street | Yes. | No. | No. | No. | No. | No. | United States mileage, 36,000. | 1911 |

## RAILROADS OPERATING DIVISIONS OR BRANCHES BY ELECTRICITY.

### Name, Location, and Mileage.

A railroad uses a standard gage, private right-of-way, M. C. B. couplers, and operates cars in trains. Elevated, subway, and interurban railways were listed in Chapter I.

Moto cars used on city streets are not listed.

These tables were compiled from the National Railway Guide, American Street Railway Investments, State and Interstate Commerce Commission Reports, Steam and Electric Railway Journals; also by correspondence, and personal inspection of properties.

| Name of railroad. | Name of division, sub-company or location. | Motor cars. | Loco-mtvs. | Route miles. | Total miles. |
|---|---|---|---|---|---|
| Boston & Maine | Concord-Manchester Branch | 12 | 0 | 17 | 30 |
| | Portsmouth-Rye Division | 21 | 0 | 19 | 20 |
| | Hoosac Tunnel | 0 | 5 | 8 | 22 |
| | Boston-Beverly | 0 | 0 | 19 | 0 |
| New York, New Haven, & Hartford. | New York Division | 4 | 45 | 34 | 100 |
| | Stamford-New Canaan | 2 | 0 | 8 | 8 |
| | Providence-Warren-Bristol | | 0 | 24 | 33 |
| | Rhode Island Company | | | | 319 |
| | Connecticut Company | | | | 755 |
| | Harlem River-New Rochelle | 4 | 15 | 13 | 63 |
| New York, West Chester & Boston. | New York-Port Chester | 60 | 1 | 17 | 63 |
| | Mt. Vernon-White Plains. | | | | |
| New York Central & Hudson River | Harlem Division: Grand Central Station, N.Y. to N. White Plains. | 137 | 47 | 24 | 70 |
| | Hudson Division: Grand Central Station, N. Y. to Hastings. | | | 20 | 80 |
| | West Shore R. R. (Oneida) | 21 | 0 | 44 | 114 |
| | New York State Rys. Co.: | | | | |
| | Schenectady, Rochester, Utica | | 0 | | 667 |
| | Syracuse-Geneva Div. (proposed) | | | 54 | |
| | Putnam Div. (proposed). | | | 12 | |
| Delaware & Hudson | United Traction, Albany | | 0 | | 96 |
| | Hudson Valley Ry | | 0 | | 149 |
| | Schenectady Ry., (1/2) | | 0 | | 132 |
| Pennsylvania R. R | Long Island R. R., 3rd. rail | 361 | 0 | 62 | 164 |
| | New York & Long I. Traction | | | | 50 |
| | Long Island Electric Ry | | | | 28 |
| | Other elec. rys. on Long Island | | | | 212 |
| | New York Terminal Division | 0 | 35 | 15 | 95 |
| | Newark-Jersey City (1/2) | 50 | 0 | 9 | 20 |
| | West Jersey & Seashore | 108 | 0 | 75 | 150 |
| | Philadelphia Terminal | | | | |
| | Cincinnati-Lebanon Division | | | | |
| Hudson & Manhattan | New York-Hoboken-Jersey City | 216 | 0 | 8 | 18 |
| | Jersey City-Newark (1/2) | 50 | 0 | 9 | 20 |
| Interboro Rapid Transit | Manhattan Elevated | 895 | 0 | 38 | 119 |
| | Interboro Subway | 910 | 0 | 25 | 85 |
| Brooklyn Rapid Transit | Brooklyn Elevated Division | 659 | 16 | | 107 |
| Bush Terminal | Brooklyn | 0 | 4 | | 25 |
| Hoboken Shore | Hoboken, N. J | 0 | 4 | | 10 |
| Philadelphia & Reading | Cape May, Del. Bay & S. P. Div | 12 | 1 | 8 | 10 |
| Philadelphia & Western | Philadelphia-Norristown | 28 | 0 | 17 | 42 |
| Norfolk & Southern R. R | Norfolk-Virginia Beach | 18 | 2 | 23 | 48 |
| Albany Southern R. R | Albany to Hudson, etc | 45 | 1 | 38 | 62 |
| Erie R. R | Rochester-Mount Morris Division | 6 | 0 | 37 | 40 |
| New York, Auburn & Lansing | Lansing to Ithaca, N. Y | | | 6 | 6 |
| International Ry | Buffalo-Lockport Division | | 2 | 18 | 25 |

RAILROADS OPERATING DIVISIONS OR BRANCHES BY ELECTRICITY.
(Continued.)
Name, Location, and Mileage.

| Name of railroad. | Name of division sub-company or location. | Motor cars. | Locomtvs. | Route miles. | Total miles. |
|---|---|---|---|---|---|
| Jamestown, Chautauqua & Lake Erie. | Jamestown-Westfield, proposed | | | 28 | ...... |
| Niagara, St. Catharine & Toronto. . | Niagara-Port Dalhousie | | 3 | ...... | 50 |
| Delaware, Lackawanna & Western. | Hoboken-Morristown, proposed | | | 34 | ...... |
| | Scranton grades, proposed | | | 34 | ...... |
| Lackawanna & Wyoming Valley. . | Wilkes-Barre-Scranton-Carbondale. | 35 | 2 | 23 | 50 |
| Wilkes-Barre & Hazelton | Wilkes-Barre-Hazelton | 6 | 0 | 31 | 34 |
| Baltimore & Ohio | Belt Line at Baltimore | 0 | 12 | 4 | 7 |
| Baltimore & Annapolis Short Line. | Baltimore-Annapolis | 12 | 0 | 26 | 35 |
| Hocking Valley Ry | Welleston & Jackson Belt Ry | 0 | 1 | 18 | 18 |
| Detroit, Monroe & Toledo S. L. . . | Detroit-Toledo | | 0 | 56 | 76 |
| Michigan Central R. R | Detroit River Tunnel | 0 | 6 | 6 | 19 |
| Grand Trunk Ry. of Canada | St. Clair Tunnel | 0 | 6 | 4 | 12 |
| | Hamilton, Grimsby & Beamsville | | 2 | ...... | 23 |
| | Hull Electric Company | | 2 | ...... | 26 |
| | Montreal Terminals, proposed | | | | ...... |
| Canadian Pacific | Aroostook Valley R. R., Me | 12 | 2 | ...... | 12 |
| | Hull, Ottawa & Aylmer Division | 10 | 2 | ...... | 26 |
| | British Columbia, Lulu Island Div | | 3 | ...... | 17 |
| | Ottawa Tunnel & Terminal | | | | ...... |
| Montreal Terminal | Montreal-local | 0 | 2 | ...... | 31 |
| Toledo & Indiana | Toledo-St. Joseph-Bryan | | 1 | ...... | 56 |
| Toledo & Western | Toledo-Pioneer-Adrian Division | | 5 | 59 | 84 |
| Scioto Valley | Columbus, O.-Chillicothe | 17 | 0 | 77 | 79 |
| Cincinnati, Geo. & Portsmouth | Cincinnati-Georgetown | | 1 | 41 | 57 |
| Illinois Traction Company | St. Louis, Peoria, Danville | 600 | 22 | 460 | 560 |
| Peoria Ry. & Terminal Company. . | Peoria-Pekin, Illinois | 10 | 0 | 19 | 20 |
| Rock Island Southern R. R | Rock Island-Monmouth | 10 | 1 | 52 | 82 |
| Chicago, Milwaukee & St. Paul | Evanston-Chicago Branch (operated by Chicago & Milwaukee Elec.) | ...... | 0 | 6 | 20 |
| | Gallatin Valley Ry., Bozeman | 4 | 1 | 25 | 30 |
| Ft. Dodge, Des Moines & Southern. | Des Moines-Fort Dodge | 10 | 6 | 70 | 141 |
| Cedar Rapids & Iowa City | Cedar Rapids-Iowa City | | 2 | 29 | 30 |
| Waterloo, Cedar Falls & Northern. | Waterloo-Waverly | | 3 | 24 | 90 |
| East St. Louis & Suburban | Illinois, coal haulage | | 2 | 20 | 31 |
| St. Louis Iron Mtn. & Southern. . | Coal Belt Ry., Carterville, Illinois. . | 9 | ...... | 15 | 18 |
| Chicago, Burlington & Quincy | Deadwood (S. D.) Central Ry | 3 | 0 | 4 | 4 |
| Colorado & Southern R. R | Denver & Interurban R. R | 16 | 0 | 45 | 54 |
| | Colorado Springs & Cripple Creek. . | 8 | 0 | 19 | 20 |
| Salt Lake & Ogden R. R | Salt Lake-Ogden | 15 | 1 | 35 | 55 |
| Great Northern Ry | Cascade Tunnel | 0 | 4 | 4 | 6 |
| Spokane, Portland & Seattle: | | | | | |
| United Rys. Company | Portland-Bay City | 4 | 1 | 27 | 30 |
| Oregon Electric Ry | Portland-Salem | 24 | 3 | 50 | 80 |
| | Salem-Eugene | | | 71 | ...... |
| Spokane & Inland Empire | Spokane-Moscow-Hayden Lake | 25 | 14 | 168 | 287 |
| Northern Pacific R. R | Snohomish-Everett, Washington | 6 | 0 | 9 | 10 |
| Portland Ry., Lighting & Power. | Portland-Canemah, Washington | 30 | 7 | 40 | 472 |
| Puget Sound Electric | Seattle-Tacoma-Renton | 141 | 7 | 37 | 200 |
| Northwestern Pacific | San Francisco-San Rafeal | 37 | 0 | 20 | 34 |
| Ocean Shore Ry | San Francisco-Santa Cruz | 40 | 0 | 53 | 53 |
| San Francisco, Oakland & San Jose | San Francisco-San Jose | 38 | 1 | 6 | 32 |
| | San Francisco-Sacramento | | | 75 | 0 |
| Northern Electric | Sacramento-Maryville-Chico | 42 | 6 | 116 | 138 |

## RAILROADS OPERATING DIVISIONS OR BRANCHES BY ELECTRICITY.
(Continued.)

Name, Location, and Mileage.

| Name of railroad. | Name of division sub-company or location. | Motor cars. | Loco-mtvs. | Route miles. | Total miles. |
|---|---|---|---|---|---|
| Southern Pacific Company | Oakland-Alameda Lines | 65 | 0 | 30 | 100 |
| | Visalia Electric Ry | 6 | 1 | 30 | 36 |
| | San Jose-Los Gatos Interurban | ...... | ...... | ...... | 40 |
| Pacific Electric Ry | Los Angeles Ry. Corporation | ...... | 18 | ...... | 600 |
| | Los Angeles & Redondo Ry | 34 | 2 | 22 | 100 |
| Los Angeles-Pacific | Los Angeles-Santa Monica-Ocean. | 121 | 0 | ...... | 260 |
| San Diego Southern Ry | San Diego-Chula Vista | 9 | 0 | 33 | 50 |
| Havana Central R. R | Havana-Guanajay | ...... | 10 | 50 | 73 |
| Havana Electric Ry | Havana-Mariana | ...... | 9 | 50 | 55 |

## RAILROAD OPERATING DIVISIONS OR BRANCHES BY ELECTRICITY.

| Name of railroad. | Name of division, sub-company or location. | Motor cars. | Loco-mtvs. | Route miles. | Total miles. |
|---|---|---|---|---|---|
| Mersey Tunnel | Liverpool-Birkenhead | 24 | 0 | 5 | 10 |
| Lancashire & Yorkshire | Liverpool-Southport-Ormskirk | 80 | 0 | 40 | 82 |
| North-Eastern | New Castle-Tynemouth | 62 | 6 | 37 | 82 |
| Central London | London | 68 | 0 | 7 | 13 |
| City & South London | London | 0 | 52 | 8 | 16 |
| Metropolitan District | London | 197 | 0 | 25 | 50 |
| Metropolitan Ry | London | 130 | 11 | 30 | 60 |
| Midland Ry | Heysham-Lancaster | 3 | 0 | 10 | 21 |
| London, Brighton & S. C. | London-S. Lon.-Crystal Palace | 46 | 0 | 23 | 62 |
| Swedish State | Kiruna-Riksgraensen | 0 | 15 | 93 | 100 |
| Thamshavn Lokken | Thamshavn-Lokken | 5 | 3 | 18 | 26 |
| Paris-Lyons-Mediterranean | Paris terminals | ...... | 3 | ...... | 40 |
| | Fayet-Chamonix | 80 | 0 | 22 | 34 |
| Paris-Orleans | Paris-Juvisy | 100 | 11 | 12 | 46 |
| West of France | Paris-Versailles | ...... | 10 | 11 | 16 |
| French Southern (Midi) | Pau-Montrejean | 30 | 6 | 65 | 75 |
| Rotterdam-Hague | Rotterdam-Scheveningen | 25 | 0 | 22 | 48 |
| Prussian State | Hamburg-Ohlsdorf-Altoona | 110 | 0 | ...... | 17 |
| | Magdeburg-Dessau | ...... | 4 | 19 | ...... |
| Bavarian State | Murnau-Oberammergau | 4 | 2 | ...... | 14 |
| | Salzburg-Berchtesgarden | ...... | ...... | ...... | 30 |
| Baden State | Weisental: Basel-Zell | 15 | 12 | ...... | 34 |
| Rhine Shore | Cologne-Bonn | 10 | ...... | 18 | ...... |
| Vienna Baden | Vienna-Baden | 19 | 2 | 18 | 33 |
| St. Polten Mariazell | St. Polten-Mariazell | 0 | 23 | 66 | 68 |
| Swiss Federal | Burgdorf-Thun | 6 | 2 | 25 | 26 |
| | Simplon Tunnel | 0 | 4 | 13 | 26 |
| Bernese-Alps | Berne-Simplon | 3 | 3 | 52 | 55 |
| Rhatische | St. Moritz-Schuls, Switz | 0 | 11 | 46 | 48 |
| Italian State | Milan-Porto Ceresio | 20 | 2 | 48 | 81 |
| | Milan-Chiavenna | 10 | 6 | 67 | 105 |
| | Giovi at Genoa | 0 | 20 | 13 | 26 |
| | Savona-San Giuseppe | 0 | 10 | 13 | 26 |
| | Bardonnechie-Modana | 0 | 10 | ...... | ...... |

## FREIGHT AND PASSENGER TRAIN SERVICE AND EQUIPMENT ON ELECTRIC RAILROADS.

| Name of railroad. | Division or service. | Motor cars. | Loco-mtvs. | Trains per dy. | Tonnage daily. |
|---|---|---|---|---|---|
| Boston and Maine | Hoosac Tunnel | 0 | 5 | 100 | ........ |
| New York, New Haven & H. | New York-Stamford | 4 | 43 | 159 | ........ |
| | Harlem River-New Rochelle | 4 | 15 | ........ | ........ |
| New York Central | Harlem and Hudson Divisions | 137 | 47 | 562 | ........ |
| Long Island | Brooklyn-Long Island | 136 | 2 | 300 | ........ |
| Pennsylvania | New York-Long Island | 225 | 0 | 310 | ........ |
| | Pennsylvania Tunnel & Terminal | 0 | 33 | 88 | ........ |
| West Jersey & Seashore | Philadelphia-Atlantic City | 108 | 0 | 90 | ........ |
| Baltimore & Ohio | Baltimore freight service | 0 | 7 | 28 | 29,600 |
| | Baltimore passenger service | 0 | 5 | 21 | 6,630 |
| Grand Trunk | Port Huron, freight and passenger | 0 | 6 | 41 | 28,343 |
| Michigan Central | Detroit, freight and passenger | 0 | 6 | 40 | 70,000 |
| Spokane & Inland | Freight service | 0 | 14 | ........ | ........ |
| | Passenger service | 25 | 0 | ........ | ........ |
| Great Northern, Cascade Tunnel | Passenger service | 0 | 4 | 5 | 5,760 |
| | Freight service | 0 | 0 | 6 | 2,690 |

See table on Train Capacity on Elevated and Underground Roads, Chapter I.

New York Central trains include storage trains between G. C. station and Mott Haven yards, light engines, fruit, express, and milk trains, shown on electric division time tables. Hudson Division has 122 trains, 88 of which handle suburban business; Harlem Division has 100 trains, all of which handle suburban business.

## TECHNICAL DATA ON RAILROAD ELECTRIFICATIONS.

### BOSTON & MAINE.

**Boston & Maine Railroad** has electrified two first-class electric interurban roads and its Hoosac Tunnel section.

Concord-Manchester division with 30 miles of track. Reference: St. Ry. Journ., Dec. 6, 1902; Oct. 12, 1907, page 539.

Portsmouth, Rye & North Hampton (N. H.) division with 20 miles of track. Reference: St. Ry. Jour., March 29, 1908.

Hoosac Tunnel section, on the main line between Albany and Boston, was electrified in 1910 and 1911. Many serious accidents had narrowly been avoided and the abolition of the risk was imperative.

The tunnel, built in 1874, has double tracks and is 4.74 miles long. The profile of the tunnel is made up of 2.25 miles of 0.5 per cent. up-grade, 0.25 miles of level track and 2.25 miles of 0.57 per cent. down-grade. The west approach to the tunnel has an up-grade of 0.8 per cent. and the east approach, 0.5 per cent.

Four Mallet oil-burning engines had been purchased in 1909, at $29,450 each, for tunnel service and to eliminate smoke, but the expedient was unsatisfactory, and the Hoosac tunnel and grades remained the limiting point of service on the Fitchburg Division.

Electrification extends from North Adams, the first station west of the tunnel, to a point 1/4 mile east of the tunnel, a total distance of about 7 miles. The total track mileage is 22.

The system used is the single-phase, 25-cycle, 11,000-volt.

Five geared locomotives for 55-m. p. h. passenger trains, and for 30-m. p. h. freight trains of 1600 to 1800 tons, were ordered from the Westinghouse Company. These are straight alternating-current locomotives, otherwise they are similar to the New Haven geared freight locomotive, No. 071, already described. Each 130-ton locomotive has a 1-hour rating of 1340 h. p., and a continuous rating on forced draft of 1120 h. p., or 83 per cent. of the 1-hour rating on 300 volts; but extra taps are arranged in the transformers so that 25 per cent. greater voltage and power can be used, when necessary.

See "Transmission and Contact Lines," Chapter XII.

Power plant embraces two 2000-kilowatt turbo-generators.

Cost of electrification is estimated at $880,000. The work was in service 7 months after its authorization. The capacity of the Fitchburg division was increased from 1000 cars to 2000 cars, per day, by the electrification.

**Reference:** E. R. J., July 1, 1911.

### NEW YORK, NEW HAVEN & HARTFORD.

**New York, New Haven & Hartford Railroad** was the pioneer in electric traction applied to steam roads. The density of traffic on its lines favors the application of electric power, primarily as a matter of economy, and for that reason there is more electric service on its former steam lines than on other roads. The use of electric power will become common, because of the density of freight and passenger traffic.

In 1895, its first steam road, the Nantasket Beach branch near Boston, 7 miles long, began the use of electric power. The writer inspected this property at that time, and remembers the use of ordinary standard steam passenger coaches and motor express cars, in 450-ton trains, hauled by two or by four 125-h. p. direct-current motors per motor car. Experimental third rail and overhead trolley lines were being tried out. Trains were operated in the method usual with steam roads, and a heavy excursion traffic was handled.

Other lines were electrified: The Berlin-New Britain branch, 12 miles, in 1897; and the Hartford-Bristol branch (St. Ry. Jour., XIII, 329, 776). N. H. Heft, electrical engineer, showed that on the branches

electrified the speed had been materially increased, the traffic had doubled, and the cost of operation had been greatly decreased.

Third-rail contacts then used were unprotected and dangerous, and for that reason electrical operation of some divisions was abandoned, while on others the 600-volt overhead trolley was used.

Interurban lines of the New York, New Haven & Hartford Railroad are controlled under the name of The Rhode Island Company and The Connecticut Company. The operation of electric interurban cars which run over steam tracks, as in the case of the road between Rockford, Rockville, and Melrose, and Berlin and Middletown, has been transferred to the New York, New Haven & Hartford, to keep the operation within the direct and immediate control of the main railroad.

**Electrification of the New York Division** in New York City was caused by legislative acts, the New York Central and the New Haven both being involved. The Grand Central Station at New York is used by both roads. New York Central plans were for short-distance terminal and suburban traffic; but the New Haven road had no suburban traffic within 15 miles of the New York City terminal, and its plans embraced the use of electric power to New Haven, Connecticut, 73 miles distant, for heavy trains, at high speed, in 4-track trunk-line service.

Electric passenger train operation between New York City and Stamford, 34 miles, began on July 5, 1907, and was completed in June, 1908. The extension to New Haven is to be completed in 1912.

**The system of electrification** adopted was the 660-volt, direct-current, third-rail over the New York Central electric zone to Woodlawn, 12 miles from the New York terminal, and 11,000-volt, alternating-current from a single overhead trolley from Woodlawn to points east. An interchangeable system was adopted, and the motor cars and freight and passenger locomotives run over any direct-current or single-phase circuit, and at any voltage. This plan marked an epoch in railroading.

**The daring of engineers** after they comprehended the necessity of a new system for general railroad work, and, with little precedent and without experience on a large scale, undertook to design a complete system, including generators suitable for the work, a new type of overhead contact, and a new type of motor for trunk-line work, has never been surpassed in the history of electrical achievements.

**Trouble occurred** when the new electric system was installed. The work was condemned as experimental, unreliable, and expensive. Opposition to the new and untried system arose from engineers of rival manufacturing companies, agents for the three-phase system, consulting engineers of high rank who had perfected the direct-current system, and college professors from whom broad-gage treatment was to be expected. American Institute discussions of the New Haven electrification show biased views:

The ancient criticisms of the deadly trolley, high cost, expensive operation, sparking commutators, etc., were repeated. Errors were made. The magnitude of long-distance trunk-line problems was not at first appreciated; and the time for design, manufacture, and experiment on equipment for the power plant, lines, and locomotives was short, and months were required to perfect the details.

The work completed and tried out is a physical success, as engineers who have carefully studied the operation of the road and the records of the maintenance of equipment testify. The motors and the overhead construction were suitable for high-speed, trunk-line railroading.

**Electric locomotives** handle most of the traffic. There are 41 passenger locomotives, rated 960 h.p. each, used for the heavy trains at speeds up to 70 m.p.h. Three 1260- to 1400-h.p. locomotives are now used for either 1800-ton freight trains at 35 m.p.h., or for 10-car, 800-ton, thru passenger trains at 50 m.p.h. Fifteen 600-h.p. switches are also used. There is some complication in the locomotives due to the necessity of providing control apparatus for operation over both direct-current third rails and alternating-current trolleys. The locomotives, of which there are five types, have been described and operating results given.

**Motor-car trains** are being installed to a limited extent. They are the heaviest equipment yet built. See description, page 251.

**Power plant** has a rated capacity of 33,100 kilowatts. Equipment and operation have been outlined, page 485.

**Maintenance costs** for track have been reduced by the use of spring-mounted motors on locomotives. The up-keep of the overhead contact line, per train-mile, is stated by members of the Board to be less than for the third-rail section.

**Estimated cost** for the electrification of the first 88 miles of track has been detailed, and totals $5,000,000.

**Operating expenses** for the 12 months ending June 30, for electrical service, are shown by the following:

| Item. | 1910. | 1909. | 1908. |
|---|---|---|---|
| Electric power transmission—maintenance | $132,297 | $3,616 | $60,079 |
| Electric locomotives—repairs and renewals | 140,983 | 256,704 | 27,860 |
| Electric equipment of cars—repairs and renewals | 41,635 | 34,715 | 49,658 |
| Transportation expense—motormen | 141,890 | 144,846 | 58,110 |
| Power-plant equipment—maintenance | 36,758 | 56,944 | 20,504 |
| Operating power plants | 230,075 | 236,422 | 127,111 |
| Purchased power for third-rail service | 97,280 | 176,293 | 39,986 |

**Financial and traffic statistics** have not yet been detailed.

President C. S. Mellin of the New York, New Haven & Hartford Railroad wrote to the Massachusetts Railroad Commission in 1908: "Our Company has been operating its passenger trains by electricity since July 1, 1908, between Stamford, Conn., and Grand Central Station, New York."

"The work has been more or less of an experimental nature, and it is probably the largest venture in the way of electric traction there is in the country, in the magnitude of the business hauled and for the distance."

"We believe we are warranted in stating that the electrical installation is a success from the standpoint of handling the business in question efficiently and with reasonable satisfaction, and the interruptions to our service are now no greater nor more frequent than was the case when steam was in use."

Vice-President McHenry reported October 31, 1910, to the Boston Board of Metropolitan Improvements, regarding the electrification of the New York division:

"The records of the New Haven Company demonstrate that under present conditions the electric train service not only fails to earn any interest upon the very large amount of capital invested, but that it has also increased the cost of operation."

"In explanation of this disappointing result, it may be stated that the experience of the New Haven Company in operating a mixed steam and electric service has proven very unsatisfactory. The annoyances and losses due to smoke, cinders, steam, and noise are at best only alleviated without being eliminated, while at the same time so large a proportion of the expense of both methods of operation is retained as to prevent the realization of the fullest degree of economy of either system. This becomes more apparent when it is considered that the power stations, if provided for passenger requirements only, will have a large unused capacity between the hours of peak load, which otherwise could be utilized to very good advantage for the transportation of freight, and more particularly as the occupation of tracks by passenger trains during the hours of peak load acts automatically to limit the simultaneous operation of freight trains at such times. Thus little or no additional investment in power houses is required for freight operation, and similarly the overhead track equipment serves equally well for both passenger and freight traffic, which makes it practicable to extend electric operation to include all classes of service at the cost of only the additional engines and the equipment of yards required for freight service."

"It therefore seems quite safe to conclude that no general substitution of electric for steam traction should be made unless the substitution is complete, including passenger and freight operation and yard switching in addition, and also that in making such substitution the operation should be extended to include the full length of run or engine district, in order to avoid the uneconomical subdivision of the present 'train run,' together with the added expense and delays incident to intermediate engine transfer stations."

The directors, in 1911, after an exacting investigation of the relative saving in fuel, and of maintenance of locomotives and overhead contact lines, by direct and by alternating current, authorized the immediate expenditure of $12,000,000 for the electrification of 250 additional miles of track, including a 63-mile freight yard on the Harlem Branch, and the New York, Westchester and Boston, 15 switcher locomotives of 600 h.p. each, 60 motor cars of 600 h.p. each, and a 16,000-kilowatt addition to

the power plant, and the use of the single-phase, 25-cycle, 11,000-volt system for the work.

**At Boston** the Boston & Albany, Boston & Maine, and the New York, New Haven & Hartford have recently been subject to such competition, by the growth of suburban electric railways at Boston, that, to regain the traffic from their terminals and to handle business with economy, they are now considering the electrification in large zones radiating from the North and South stations at Boston.

The present electrification plans for Boston embrace 462 miles of single track and the estimated cost, given to the Board of Metropolitan Improvements, October 31, 1910, is $32,750,000. The companies are not opposed to electrification but state that it is more practical at first to restrict the substitution of electricity for steam to a few of the more important of 20 routes, subsequently extending the system as rapidly as consistent with the financial conditions and public needs. The electrification of the Boston to Readville, and the Boston to Beverly divisions was promised for 1912. Elec. Ry. Jour., Nov. 19, 1910.

#### References on New York, New Haven & Hartford Railroad Electrification.

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Providence, Warren & Bristol R. R., 14 miles, S. R. J., March 1, 1902.

Middletown-Berlin-Meriden, 17 miles, S. R. J., Sept. 21, 1907.

Hartford-Melrose Electrification, 25 miles, S. R. J., Dec. 7, 1907.

New Canaan-Stamford branch, 8 miles, 11,000 volts, G. E. series-repulsion motors, E. W., Jan. 18, 1908, p. 139; E. R. J., May 15, 1909, p. 901.

Westinghouse: Reason for Alternating-current, Comparative Cost of A.-C. and D.-C. Systems, S. R. J., Dec. 23, 1905.

Sprague: An Unprecedented Railway Situation (Objections to the New Haven Plan for Trunk-line Electrification), S. R. J., Oct. 21 and 28, 1905, Facts and Problems Bearing on Electric Trunk-Line Operation, A. I. E. E., May, 1907.

Lamme: The Alternating-current System, N. Y. Ry. Club, March 16, 1906; S. R. J., March 24 and April 14, 1906; Elec. Journal, April, 1906; July, 1906.

McHenry: Reasons for Adopting Electricity, S. R. J., Aug. 17 and 24, and Oct. 12, 1907. Electrification, Ry. Age, Aug. 16, 1907.

Organization: S. R. J., Oct. 12, 1907, p. 608.

Murray: The Single-phase Distribution, A. I. E. E., Jan., 1908. Steam and Electric Performance, A. I. E. E., Jan. 25, 1907. Log of New Haven Electrification, A. I. E. E., Dec., 1908; Steam Locomotive, Fuel and Maintenance, A. I. E. E., Jan., 1907, p. 148; Analysis of Electrification: A. I. E. E., April and June, 1911.

Boston Situation: E. R. J., Nov. 19, 1910.

See references under History, Electric Systems, Motors, Locomotives, Transmission and Contact Lines, Power for Trains, Power Plants, and Cost of Electrification.

### NEW YORK CENTRAL.

**New York Central & Hudson River Railroad** electrification embraces 4 main tracks from the Grand Central Terminal, New York, to Mott Haven junction, 5 miles from the terminal, thence continuing north on the Harlem Division to North White Plains, a total distance of 23.5 miles, and northwest on the Hudson Division to Hastings, 19.5 miles from the terminal. In time the work will be extended on the Hudson Division to Croton, 34 miles; and over 12 miles of the Putnam Division.

Trains were first operated by electricity in the terminal Nov. 11, 1906, and the last steam train was taken off July 1, 1907.

The adoption of electric traction for trains for the most important terminal and suburban work in the country marked an epoch in the application of electricity to train haulage, second only to the work at Baltimore in 1896.

Grand Central Station yards, now being excavated, will have 42 main-line tracks on the street level and 24 suburban tracks, with loop tracks, about 12 feet below the level of the upper 42 tracks. The terminal with steam service had a capacity of 366 cars, while with electric service it will have 1149 cars. The cost of producing space for a car, exclusive of the cost of the station, is given as $30,000. Electric motive power changed old conditions, and it is now only necessary to provide sufficient head room for trains. Two-thirds of this work was completed before 1911.

Electrification was compulsory. An act of the Legislature dated May 7, 1903, required electric motive power to be used after July, 1907. This act followed several accidents, caused by exhaust steam and smoke in a subway, and one, on January 8, 1902, was unusually serious. Public comfort, safety, and convenience demanded the change.

**A commission of engineers** appointed in 1904 to plan and execute the work was comprised of J. F. Deems and W. J. Wilgus of the New York Central, B. J. Arnold, F. J. Sprague, and George Gibbs, Consulting Engineers, with its secretary, E. B. Katte. These engineers fixed the principles and policies which were afterward carried out under the jurisdiction of the chief engineer of electric traction, E. B. Katte.

**The system** adopted was the 660-volt, direct-current, with a third rail, the only system then developed for railroad traction.

Power stations, each with a capacity of 20,000 kilowatts, located at Port Morris and at Yonkers, have been described.

Transmission lines send 11,000-volt three-phase current to nine rotary converter substations, and direct current to the third rails.

Electric locomotives are used for hauling thru trains; but motor cars are used for the suburban passenger service. The annual locomotive miles are now 1,200,000. There are 47 locomotives of 2200 h. p., 137 motor cars of 480 h.p., each, and 63 trail coaches.

**Cost of electrification** and other work to 1910 have been as follows:

| | |
|---|---|
| Grand Central Station | $11,000,000 |
| Real estate | 10,500,000 |
| Four-tracking and station improvements | 6,000,000 |
| Elimination of grade crossings | 500,000 |
| Post office and office buildings, over tracks | 4,000,000 |
| Electrification of 125 miles of single track | 10,700,000 |
| Total cost to Croton and to N. White Plains (estimate) | $23,550,000 |
| Estimated cost of all terminal improvements | $160,000,000 |

**Operating expenses** for the 12 months ending June 30, for electrical service, are shown by the following:

| Item. | 1910 | 1909 | 1908 |
|---|---|---|---|
| Electric power transmission—maintenance | $........ | $63,256 | $217,451 |
| Electric locomotives—repairs and renewals | .......... | 31,320 | 45,888 |
| Electric equipment of cars—repairs and renewals | .......... | 19,547 | 33,898 |
| Transportation expense—motormen | .......... | 182,108 | 194,412 |
| Power plant equipment—maintenance | .......... | 22,384 | 38,664 |
| Operating power plants | .......... | 124,193 | 125,995 |
| Purchased power | .......... | 2,301 | 2,483 |

**Proposed work** for 1912 embraces the electrification of the entire freight line on the west side of Manhattan Island. This is a most extensive project since these freight tracks bring to New York City daily, and largely between midnight and morning, a large proportion of the food supply for Manhattan Island. There are practically no passenger trains moving between 1:00 and 6:00 A. M. With the freight service added, the load factor of the steam power plants will be raised, decreasing the cost of power, also greatly decreasing the investment per train-mile and per ton-mile hauled.

**References on New York Central & Hudson River Railroad Electrification.**

Arnold and Potter: Tests for Power Required, A. I. E. E., June, 1902.
Wilgus: Electrification, S. R. J., Oct. 8, 1904.
Descriptions and Tests: S. R. J., Nov. 19, 1904.
Descriptions, general: S. R. J., 1905–6–7–8, particularly Oct. 12, 1907.
Motor Cars and Coaches: S. R. J., Nov. 4, 1905; trucks, S. R. J., April 28, 1906.
Power house: S. R. J., Sept. 29, 1906; Oct. 12, 1907.
Transmission Lines: S. R. J., Nov. 18, 1905; Oct. 12, 1907.
Substations: S. R. J., Nov. 3, 1906; Oct. 12, 1907.
Sprague: Comparison with N. Y., N. H. & H. R. R., A. I. E. E., May 16, 1907, p. 746.

Wilgus: Financial Results from Operation, Steam versus Electricity, A. S. C. E., Feb., 1908; S. R. J., March 7, 1908; Ry. Age, March 6, 1908.
Auxiliary Lines: Ry. Age Gazette, July 19, 1907, p. 67.
Organization and Maintenance: S. R. J., Oct. 12, 1907.
Maintenance Plant at Harmon, N. Y., S. R. J., June 8, 1907.
Arrangement of Tracks at Grand Central Terminal, Ry. Age, Oct. 7, 1910; S. R. J., Nov. 18, 1905.

## WEST SHORE RAILROAD.

**West Shore Railroad** is one of the New York Central lines. The company electrified 44 miles of road, or 114 miles of track, between Utica and Syracuse, in 1907, to shut off threatened competition of a chain of electric roads being built by strong interurban railways between Buffalo and Albany. The work was carried out by subsidiary companies, the Utica and Mohawk Valley, and the Oneida Railway.

The road between the cities runs on the private right-of-way, over the 2, 3, and 4 tracks of the West Shore Railroad, both steam and electric trains using the same tracks, and over the city streets at terminals.

Power from Niagara Falls is transmitted along the right-of-way on a steel-tower transmission line, to four rotary converter substations, 11 miles apart, where it is transformed from 60,000 volts and converted to direct-current at 600 volts. The contact line is a 70-pound protected third rail, except in the cities where a common 600-volt trolley is used.

One- or two-car trains run half-hourly from each terminal.

### References.

Descriptions, Tests, Service, Schedules, S. R. J., May 19, 1906; June 8, 1907; Oct. 12, 1907, p. 581; G. E. Review, Aug., 1907.

## LONG ISLAND RAILROAD.

**Long Island Railroad,** which is a subsidiary company of the Pennsylvania Railroad, since 1904 has operated electric trains from its Brooklyn terminals to points east on Long Island with numerous north and south branches, in a densely populated district. Much of the road in Brooklyn has been elevated to abolish grade crossings. Good connections are made in Brooklyn with the Interborough Rapid Transit subway and with the Brooklyn Elevated Railroad. The principal terminal, at Long Island City, is operated by steam locomotives.

Long Island Railroad was the first large railroad to electrify its line on an extensive scale. The work began on its Atlantic Avenue line and on its Rockaway division. About 42 miles of route or 98 miles of track

were completed in 1905, making the most extensive electric road for that period. About 44 miles of route or 100 miles of track were electrified prior to 1909; about 62 miles of route or 164 miles of track prior to 1910.

Pennsylvania Railroad tunnels to and from Manhattan Island, which were completed in 1910, provide service outlets from New York to points near Long Island City, and further east to all points on the south side of Long Island, 24 miles distant.

"The electrification of the Long Island Railroad presents the first transformation of a regular steam road to electric traction. Branch lines of importance have been operated electrically, but this is the first extended electrification of main tracks."

"The rapidity of traffic expansion (after electrification) is indicated by the fact that service provided for the year 1906 is four times the 4th of July service in 1902."

"The record breaking piece of work was remarkable. In 18 months the power station was constructed and ready for operation; 100 miles of track were electrified, 25 miles of conduit and 24 miles of pole line were constructed; 250 miles of high-tension conductors were erected; 5 substations were built and equipped; 130 steel motor cars were built and equipped; 85 trail cars equipped; and the operation of the road begun" in 1905. Lyford, in Electric Journal, Jan., 1906.

**Direct current** from a 600-volt third-rail line is used for power.

Electric locomotives are not used for passenger or freight service.

Motor-car trains handle the suburban passenger service. Equipment consists of 136 steel motor cars, each weighing 41 tons and equipped with two 200-h. p. motors per car for Brooklyn-Long Island service, and 66 wooden coaches each weighing 31 tons, for the above; also 225 steel motor cars, each weighing 52 tons and equipped with two 210-h. p. motors per car for the New York-Long Island service. These have been described. Six-car trains are operated ordinarily, but trains of 8 to 12 cars are used for heavy excursions. Speeds up to 55 m. p. h. are common and a schedule speed of 25 m. p. h. is maintained with stops 1.6 miles apart.

The 32,500-kilowatt steam plant, used jointly by the Long Island and Pennsylvania, has been described.

**Results from the electrification** were definitely announced by the Long Island Railroad in 1909. With 120 miles of its track electrically operated, in 1908, the road was operating at sufficiently low cost, below steam operation, to pay the interest on the extra investment, and to yield a handsome surplus. The road was but recently operated with a deficit. The results are surprising, in view of the incompleteness of the installation and the large expenditures at terminals, power plant, etc., from which only a small advantage is as yet derived.

Long Island Railroad, in October, 1910, began the operation of electric trains from the Pennsylvania Railroad station in New York to Jamaica and other points in Long Island.

OPERATING DATA FOR THE YEAR. LONG ISLAND RAILROAD. 1908.

| | |
|---|---|
| Cost per car-mile for electric railway service | 17.80¢ |
| Cost per car-mile for steam railway service | 27.95¢ |
| Ton-miles in electric passenger service | 180,129,860 |
| Car-miles in electric passenger service | 4,945,719 |
| Car-miles in steam passenger service | 2,500,000 |
| Train-miles (3.94 cars per train) | 1,251,877 |
| Maintenance expense of cars per car-mile | 0.76¢ |
| Maintenance of electric equipment per car-mile | 2.1 to 3.0¢ |
| Power-plant expenses per car-mile | 3.3 to 3.5¢ |
| Direct current kilowatts used for traction | 16,210,962 |
| Efficiency from power-house to substation output | .813 |
| Watt-hours per ton-mile at substations | 90 |
| Watt-hours per ton-mile at power house | 110 |
| Cost per kw-hr. at power house | 0.697¢ |
| Cost per kw-hr. at cars | 1.467¢ |

**Operating expenses** for the 12 months ending June 30, for electrical service of the Pennsylvania Railroad are shown by the following:

| Item. | 1910. | 1909. | 1908. |
|---|---|---|---|
| Electric power transmission—maintenance | $ | $96,704 | $87,008 |
| Electric locomotives—repairs and renewals | | | |
| Electric equipment of cars—repairs and renewals | | 104,854 | 65,632 |
| Transportation expense—motormen | | 92,339 | 81,158 |
| Power-plant equipment—maintenance | | 11,885 | 9,590 |
| Operating power plants | | 139,460 | 149,754 |
| Purchased power for third-rail service | | 210,598 | 198,610 |

### PENNSYLVANIA TUNNEL & TERMINAL.

**Pennsylvania Railroad Company,** thru its late President, A. J. Cassatt, conceived and planned a system of tunnels, terminals, yards, and bridges to the north, to unite New Jersey, Manhattan, Long Island, and New-England with an all-rail route. The tunnels and stations are no longer a dream. The stupendous project, requiring the expenditure of $160,000,000 became practical, because of the development of safe and reliable operation of heavy trains by electricity thru long tunnels and on heavy grades to an underground terminal station.

**Pennsylvania Tunnel & Terminal Company** operates the terminal station and yards of the Pennsylvania Railroad at New York City. This station has from 21 to 36 tracks, about 3600 ft. long. There are two tunnels between Manhattan Island and New Jersey under the Hudson

River, four tunnels between Manhattan Island and Long Island City under the East River, and extensive terminal and storage yards at Sunnyside on Long Island. The work on Manhattan Island was completed in 1910.

The route miles of the Pennsylvania Tunnel and Terminal Company's tracks between Harrison, N. J., and Sunnyside Yards, L. I., are 14.9, of which 9.83 are on the surface, 2.29 under the two rivers, and 2.78 underground. The track mileage which has been arranged for electric power now aggregates 95, inclusive of terminal yards.

The direct-current 660-volt system was adopted because its subsidiary road, the Long Island, had previously expended $1,000,000 on its direct-current equipment. The power station has been described. The third-rail is T-shaped, 4 inches high, with a 4-inch top face, weighs 150 pounds per yard, and is equivalent to a 2,475,000 c.m. copper conductor.

Electric locomotives are used for Pennsylvania, Chesapeake & Ohio, and other thru trains in and out of New York City.

Motor cars are now used by the Long Island Railroad for all thru and suburban trains to all points less than 30 miles distant on Long Island.

Service planned for the ultimate passenger work is 600 Long Island and 400 Pennsylvania trains in and out of the station daily. The train service in 1911 consisted of a total of 88 Pennsylvania and 310 Long Island trains in and out per week-day.

A rapid transit electric motor-car train service is to be operated jointly with Hudson & Manhattan Railroad, in 1911, between Newark and the old Pennsylvania terminal in Jersey City, 9 miles, and the H. & M. tunnels to the lower part of Manhattan Island.

### WEST JERSEY & SEASHORE.

**West Jersey & Seashore Railroad,** of the Pennsylvania Railroad, extends from Camden, opposite Philadelphia, to Atlantic City.

The service is largely passenger work on a trunk line, 65 miles long, with service at frequent intervals over the entire length, and with service at one end of the line of some density. During the height of the summer season, 3-and 4-car trains run on a 15-minute headway in each direction, at high speeds. Baggage, mail, express, milk, and other motor cars run either in or separate from the passenger trains. The winter service, 10,000 car-miles per day, is about one-half of the summer service.

The electric construction work was completed within 9 months of the commencement of the work, which is remarkable. Operation began July 1, 1906.

**Miles of main route** are 65, with a 10-mile branch, near the middle of the line. The total electric mileage is 150.

**Reasons for electrification** were entirely economical. The traffic had

not been decreasing, but the expenses were increasing. There was some local business, along the route which could be handled more economically and expeditiously by electric traction than was possible with steam. The electrification also forestalled a proposed competing parallel electric road.

**The electric system,** chosen in 1906, was the direct-current, 675-volt, with an unprotected top-current third rail.

**Power station** contains twelve 350-h. p. Stirling boilers and four 2000-kw., 6600-volt, 25-cycle turbo-generators. Transmission line consists of 70 miles of duplicate 33,000-volt line on 45-ft. wooden poles.

Substations for the 75 miles of route number 8, each containing 2 or 3 rotary converters, of 500, 750, or 1000 kilowatts; total capacity 17,000 kilowatts. Traffic in winter is light and the expense for up-keep of the rotary converters per train-mile then doubles. The operating expense of the rotary converter substations for the cross-country service furnished are a handicap which is proportionately greater than for terminal and congested traffic. Freight trains cannot be handled economically with the system and equipment installed.

**Motor cars** number 93 for passenger, baggage, and mail service, weighing 48 tons, and 15 steel motor cars weighing 52 tons. Two 240-h. p. motors are used per car. Cars are given a general overhauling in the shops every 50,000 miles. The motors are painted, the fields removed and cleaned, the armatures blown out, and the fields and armatures are given a coat of insulating paint. Controllers and minor equipment are given a general cleaning and painting at overhaulings, at least once per year. Car detentions average one per 15,000 miles. Speed in thru service averages 43 m. p. h. and in local service 26 to 32 m. p. h.

**Results** from operation have been excellent:

**Gross earnings** increased at the rate of less than 2 per cent. per year until the road was electrified; while each year after electrification the gross earnings have increased 11 per cent. Electrification made the road popular.

**Operating expenses** during 1908 were 20.46 cents per car-mile for electric service, as against 22.30 cents per car-mile for steam service. During 1909 operating expenses were 18.75 cents; and during 1910 were 18.19 cents per car-mile. The saving over steam was nearly 7 cents per car-mile which, on over 4,550,000 car-miles per year, was over $300,000 per year in favor of electrical operation. The cost of steam service is increasing. The average cars per train with steam service are seven, or twice that for the electric service.

**Cost of electrification** to 1911 is given as $3,650,000. The electrical investment now produces a saving of 8.2 per cent. to pay the annual interest charges on the investment.

OPERATING DATA. WEST JERSEY & SEASHORE.

| Year. | 1910. | 1909. | 1908. | 1907. |
|---|---|---|---|---|
| Kilowatt hours from power plant | 28,312,500 | 23,551,200 | 22,887,600 | 21,118,800 |
| Kilowatt hours from substations | 21,972,300 | | | |
| Efficiency of h.t. lines and substations | .816 | .784 | .738 | .722 |
| Cost of coal per 2000 pounds | $2.235 | | | |
| Cost per kw-hr. at power plant, ¢ | 0.542 | 0.555 | 0.592 | 0.680 |
| Pounds of coal per kw-hour | 3.250 | 3.300 | 3.370 | 3.670 |
| Cost of power, total | $153,449 | | | |
| Car-miles, 3.5 cars per train | 4,552,532 | 4,107,609 | | |
| Total cost per mile, electric | $.1819 | $ 1875 | $.2046 | |
| Total cost per car-mile, steam | $.2500 | | $.2230 | |

**Philadelphia terminal** electrification has been worked out by a board of engineers appointed by the Pennsylvania road. The plans developed and adopted include the electrification of all suburban lines radiating from the Broad Street, North Philadelphia, and West Philadelphia stations. The estimated cost of the electrification was $14,000,000.

**References on Pennsylvania Railroad Electrifications.**

Long Island R. R:

Lyford and Smith: A. I. E. E., Nov., 1904; Smith: S. R. J., June 9, 1906.

Lyford: General outline of work, Elec. Journal, Jan., 1906.

Cars: 37-ton, S. R. J., Aug. 11, 1906; Ry. Age, Aug. 12, 1906.

Trucks: Of steel passenger car, E. R. J., June 27, 1908.

Electrification: S. R. J., Nov. 19, 1904, Nov. 4, 1905; Oct. 12, 1907.

Power House: S. R. J., Jan. 5, 1905; April 7, 1906; Oct. 12, 1907, p. 587.

Operating Statistics: Ry. and Engr. Review, Feb. 12, 1908; E. R. J., Mar. 26, 1911, p. 532.

McCrea: New York R. R. Club, March, 1911; Ry. Age March, 1911, p. 689.

Pennsylvania Tunnel & Terminal R. R.:

General data: S. R. J., Oct., 1907, p. 587.

Contract: $5,000,000 with Westinghouse for power house, substations, and locomotives for work from Newark, N. J., to Jamaica, L. I., S. R. J. Nov. 7, 1908.

Locomotives: 157-ton, 2500-h. p., E. R. J., Nov. 6, 1909; R. R. Age, Nov. 5, 1909.

West Jersey and Sea Shore R. R.:

Descriptive: S. R. J., Dec. 23, 1905; Nov. 10, 1906; Oct. 12, 1907.

Operating Statistics: E. R. J., March 26, 1911, p. 532.

Wood: Operation of the W. J. & S., A. I. E. E., June, 1911; E. R. J., July 1, 1911.

Philadelphia Terminal:

Proposed Electrification: E. T. W., Jan. 14, 1911, p. 44; E. W., June 11, p. 1578.

**HUDSON & MANHATTAN.**

Hudson & Manhattan Railroad Company operates tunnel lines from a station near Grand Central Station, New York City, thence south and

west to Hoboken, via two tunnels under the Hudson River, thence south in New Jersey to Jersey City, thence east via two tunnels under Hudson River to the Hudson Terminal Building in lower New York, near the Broadway connections to the Rapid Transit subway. Total route length 8; mileage 18. An extension runs from Jersey City west to Newark, N. J., 9 miles, and connects with the main line of the Pennsylvania Railroad.

**Motor cars** consist of 216 steel cars which now run in 6-car trains. Each car is a 35-ton motor car, equipped with two 160-h. p. motors.

Traffic is dense but the haul is short. Trains carry 50 per cent. more passengers per car-mile than New York subway trains.

The system is the 660-volt, direct-current, third-rail.

**References.**

Maps, steel tubes, third rail, and substations, S. R. J., Nov. 25, 1905; E. R. J., Feb. 29, 1908. Cars: S. R. J., June 8, 1907; E. R. J., Oct. 2, 1909. Passenger stations: S. R. J., March 9, 1907. Power plant: E. R. J., March 5, 1910.

## BALTIMORE & ANNAPOLIS.

**Baltimore & Annapolis Short Line,** owned by the Maryland Electric Railways, runs entirely on a private right-of-way from the B. & O. station at Baltimore to Annapolis. Passenger service of a high grade began in January, 1909. Miles of route are 26 and the total mileage is 35.

Reasons for change from steam to electricity were: "Increased car mileage, more frequent service, express service at least as fast, cleaner service, and the sentimental and indefinable inherent attraction in electrical operation." Competition with parallel lines also existed.

The equipment consists of twelve 50-ton, 400-h.p., passenger cars with M. C. B. couplers for interchangeable steam railroad service.

The electric system chosen was the single-phase, 25-cycle, with a 6,600-volt trolley. Pantographs are used as collectors.

Power is purchased. The one substation is located near the middle of the line and contains three 300-kv-a., 22,000- to 6,600-volt step-down transformers. The substation is inspected daily.

Operating results have been excellent, because of good management and equipment. The road runs entirely on a private right-of-way. Baltimore and Annapolis steam service consisted of 14 trains each way per day. The present daily car-mileage is 2500 and the schedule speed is 32 m. p. h.

**Reference.**

Whitehead, A. I. E. E., July 1, 1908, describes the change from steam to electric power, gives data on several plans, speed-time and power curves, cost of equipment, and cost of operation by either direct current or alternating current.

### BALTIMORE & OHIO.

**Baltimore & Ohio Railroad** in 1905 began the use of electric power for its switching service and for train haulage thru the belt line tunnel at Baltimore. The 12 locomotives now used have been described.

The initial management of the electrical property, after the introduction of electric power, was bad. The feeders were small, the first rail bonds were inadequate, and the new rail bonds placed around the rail joints were stolen. The overhead third rail (a double channel) was a failure because of its rigidity and the corrosion by steam locomotive gases. A 70-pound third rail was then located on the ties. A sectionalized third-rail scheme which was tried was a failure.

Operating and maintenance costs of an antiquated power plant, containing high-speed, non-condensing engines, were heavy. The power load was difficult to handle because the locomotives carried heavy loads up the grades and used no power on the down grades.

The locomotives themselves received but little attention, and they were allowed to depreciate. They had a hard time for existence, but they won out. Train haulage by electric power was made successful, and the installation, as a whole, marked an epoch in railroading.

The 1896 locomotives were successful, considering both the importance of the installation and the design of equipment 15 years ago.

Power is now purchased and is delivered thru a 3000-kilowatt substation. The maximum fluctuating load, when 4 locomotives or 2 trains are operated, is about 4500 kilowatts. More than 2 trains are not allowed on the line at one time. The locomotives make 200,000 miles, and haul 60,000,000 ton-miles up the grades, per annum.

The equipment is now in the hands of competent railroad men and excellent operating results are being obtained.

Enthusiasts supposed that this installation was a forerunner of large and immediate electrifications of steam railroads. It has been stated that, in 1905, the officials of the railroad, being pleased with the physical and financial results, had estimates made for electric service over the Allegheny mountains. These estimates were based on the haulage of trains of double length, at double speed, making a great reduction in the number of trains. Locomotives were to be controlled by a single crew, congestion was to be prevented, time saved, and capacity gained in service. The estimates for electrification showed that suitable locomotives could be purchased, but the enormous cost of copper with the direct-current system, and the placing of rotary converters 3 to 4 miles apart, made electrification absolutely prohibitive. High voltages had to be used for the contact line, to reduce the number of transformer substations.

**Operating expenses** for the 12 months ending June 30, for electrical service, are shown by the following:

| Item. | 1910. | 1909. | 1908. |
|---|---|---|---|
| Electric power transmission—maintenance | $ | $5,525 | $11,898 |
| Electric locomotives—repairs and renewals | | 7,776 | 16,475 |
| Electric equipment of cars—repairs and renewals | | 0 | 0 |
| Transportation expenses—motormen | | 16,087 | 15,515 |
| Power-plant equipment—maintenance | | 26,852 | 9,275 |
| Operating power plants | | 71,284 | 74,254 |

**References on Baltimore & Ohio Railroad Electrification.**

Early Plans: Elec. Engr., Nov. 6, 1895, Mar. 4, 1896; S. R. J., March 14 and Aug. 22, 1903; July, 1895. S. R. Review, April 26, 1902.

Third rail: S. R. J., March 2 and Dec. 14, 1901; July 30, 1904.

Muhlfield: Steam versus Electric Locomotives, N. Y. R. R. Club, Feb., 1906; S. R. J., Feb. 24, 1906.

Hutchinson: Mountain Electrification on Altoona grades, Elec. Age, 1904.

Davis: Operating Data, A. I. E. E., Nov., 1909, p. 1330.

See technical descriptions of Electric Locomotives in Chapter VIII.

## MICHIGAN CENTRAL.

**Michigan Central Railroad** hauls its freight and passenger trains thru its new Detroit River 7860-foot tunnels between Detroit, Michigan, and Windsor, Ontario, with six 100-ton electric locomotives. Service began in August, 1910. Power is purchased from the Detroit Edison Co., and two 1000-kilowatt motor-generators and a storage battery are used. The direct-current, 660-volt, third-rail system is used on 6 miles of route and 19 miles of track. See references under description of the locomotive.

The present daily traffic is 1100 freight cars and 16 passenger trains.

## GRAND TRUNK.

**Grand Trunk Railway** electrified its tunnel under the St. Clair River between Port Huron and Sarnia in 1908. The length of the electric zone is 4 miles but including the tracks, which are 4 to 10 deep at terminals, the electric mileage is 12.

This was the first American electrification of an important tunnel wherein a high-voltage trolley was used. The tunnel has a small bore, and 3300 volts was used for safety, and because it was high enough for the short distance.

The six 66-ton electric locomotives, motors, power plant, service, economy, etc., were outlined in the technical description of locomotives.

Grand Trunk Railway had plans made in 1910 for the electrification of its road near Montreal. The project embraces the city passenger

terminal and the road to the Victoria bridge over the St. Lawrence River; and it has purchased the Montreal & Southern Counties Electric Railway, a 6-mile road between Montreal and St. Lambert.

### ERIE RAILROAD.

**Erie Railroad Company** has, since June, 1907, operated a 37-mile single-track electric branch, between Rochester and Mt. Morris, N. Y., for passenger service over steam railroad tracks.

Electrification was for the purpose of preventing competition and for economy of operation. There was also a desire to try out electric traction.

Power is transmitted over the Niagara, Lockport & Ontario Power Company's 3-phase, 165-mile line, at 60,000 volts. A substation, located at Avon near the middle of the road, contains three 750-kw., 60,000- to 11,000-volt transformers. Single-phase, 25-cycle, 11,000-volt power is used.

Cars consist of six 48-ton motors, and six 28-ton coaches. Three or four car trains are operated on the multiple-unit plan. Each motor car has four 100-h.p. motors.

Operating results published are to the effect that the gross earnings for passenger service, based on ticket sales, have increased 40 to 50 per cent.; also that the operating cost under the usual operating and maintenance headings of the Interstate Commerce Commission averages 18 cents per car-mile. The motor-car mileage per annum is 250,000, and the trail car mileage 75,000.

**Operating expenses** for the 12 months ending June 30, for electrical service, are shown by the following:

| Item. | 1910. | 1909. | 1908. |
|---|---|---|---|
| Electric power transmission—maintenance | $....... | $1,874 | $2,475 |
| Electric locomotives—repairs and renewals | .......... | 0 | 0 |
| Electric equipment of cars—repairs and renewals | .......... | 11,286 | 14,796 |
| Transportation expense—motormen | .......... | 5,379 | 5,300 |
| Power-plant equipment—maintenance | .......... | 0 | 0 |
| Operating power plants | .......... | 213 | 580 |
| Purchased power | .......... | 15,941 | 17,499 |

**References.**

Operation: S. R. J., Oct. 12, 1907, pp. 629 and 650; June 19, 1909.

Power Transmission: 165 miles, S. R. J., July 14, Aug. 25, Dec. 8, 1906.

Lyford: on Operation, A. I. E. E., Dec. 11, 1908, p. 1696.

W. N. Smith: Ry. Age, Oct. 11, 1907, S. R. J., Oct. 12, 1907.

Proposed Electrification of Birmingham-Corning, N. Y., 76-mile division, to head off competition, S. R. J., Dec. 23, 1905, p. 1118.

## CHICAGO, BURLINGTON & QUINCY.

**Denver & Interurban Railroad,** a part of the Colorado and Southern, in turn, a part of the Chicago, Burlington & Quincy, is a high-grade railroad between Denver and Boulder, Colorado. About 44 miles of track were electrified in 1906.

The reason for electrification was due to the opportunity to utilize water power to reduce the motive-power expense of steam passenger train operating on heavy grades.

The system used is the single-phase, 25-cycle, 11,000-volt for a. c.-d. c. service. The overhead work includes catenary construction, phono-electric trolley wire of high tensile strength, galvanized steel brackets, and wooden poles.

Power is furnished by the plant of the Northern Colorado Power Co., from two 1000-kw. single-phase turbo-generators.

Motor cars are 16, each equipped with four 125-h. p. geared motors. The weight of the motor cars is 58 tons, of the coaches is 37 tons, and two-car trains are ordinarily operated.

### References.

Deadwood Central R. R.: Black Hills grades, Deadwood to Leads City, S. D., S. R. J., Nov. 22, 1902, p. 841.
Denver & Interurban R. R., S. R. J., Sept. 24, 1904; Oct. 2, 1909.
Colorado Springs & Cripple Creek Ry., E. R. J., Oct. 2, 1909.

**Operating expenses** for the 12 months ending June 30, for electrical service, are shown by the following:

| Item. | 1910. | 1909. | 1908. |
|---|---|---|---|
| Electric power transmission—maintenance | $........ | $1,157 | $1,526 |
| Electric locomotives—repairs and renewals | .......... | 0 | 0 |
| Electric equipment of cars—repairs and renewals | .......... | 2,167 | 2,840 |
| Transportation expenses—motormen | .......... | 5,198 | 5,333 |
| Power-plant equipment—maintenance | .......... | 601 | 436 |
| Operating power plants | .......... | 3,000 | 3,177 |
| Purchased power | .......... | 11,000 | 9,645 |

## SPOKANE & INLAND EMPIRE.

**Spokane & Inland Empire Railroad** furnished the first example of the extensive use of single-phase railroad equipment. The road has a private right-of-way and private terminals, freight and passenger. Water power is used to haul all electric trains. Operation started in 1906.

Route miles approximate 180; single-track mileage is 287; and the mileage of the single-phase road is 162. The longest runs are from Spokane south to Colfax, 77 miles, with a branch to Moscow, 91 miles from Spokane.

Reasons for electrification have been stated as speculative, and a desire to open up a new country. The use of electric power was due to the splendid water powers available.

The system used is the a. c.-d. c., single-phase, 6600-volt, 25-cycle. The equipment consists of 21 motor cars, each equipped with four 100-h.p. motors; six 500-h. p. locomotives, and eight 680-h. p. locomotives.

The direct-current equipment is used for a street railway and for a direct-current, 46-mile road to Hayden Lake.

Transmission lines consist of 116 miles of 45,000-volt, No. 2 copper wire. Catenary lines are supported from brackets on cedar poles. Substations consist of 11 transformer houses, spaced about 10 miles apart, each containing two 375-kw., 45,000-volt to 6600-volt, oil-insulated, self-cooled transformers.

**References on Spokane & Inland Empire Railroad Electrification.**

General: S. R. J., Feb. 11, Oct. 14, 1905; Apr. 27, 1907.
Cars: S. R. J., Nov. 10, 1906.
Water Power: S. R. J., March 9, 1907; Jan. 11, 1908; E. W., Oct. 10, 1908.
Load and Batteries: S. R. J., Sept. 28, 1907.
Report to State Railroad Commissioners: S. R. J., Nov. 2, 1907.
Annual Report: June 30, 1908, E. R. J., Oct. 10, 1908.
Ingersoll: Cost of Equipment, Elec. Journal, Aug., 1906.

## GREAT NORTHERN RAILWAY.

**Great Northern Railway** electrified 6 miles of tunnel and terminal track at Cascade Mountain tunnel, in Washington in 1909. The tunnel is 14,400 ft. long, on a 1.7 per cent. grade.

The system is the 25-cycle, 6,000-volt, 3-phase.

Power plant, of 7,500-kw. capacity, and line, have been described. Cost of electrification was about $1,620,000.

Electric locomotive equipment consists of four G. E., 115-ton articulated machines, each equipped with four 500-volt, one-speed, geared, three-phase motors, rated 1900-h. p. on forced draft. These are the first three-phase locomotives in America. The installation, see technical description, is quite different from the three-phase installations made by Ganz, Brown-Boveri, Westinghouse, and Oerlikon.

Service is infrequent but heavy, and 1900-ton freight trains are hauled up the grade by three locomotives per train, while passenger trains require two locomotives per train.

Electric roads controlled by the Great Northern-Northern Pacific include the Oregon Electric, the United Railways of Portland, and others.

### References.

**References on Great Northern Railway, Cascade Tunnel Electrification.**

General: G. E. Bulletin 4537, Sept., 1907; G. E. Review, Slichter, Aug., 1910.
General: S. R. J., May 11, Dec. 28, 1907; Oct. 31, 1908.
System: Hutchinson, A. I. E. E., Nov., 1909.
Contact Line: Deneen, A. I. E. E., Nov., 1909.

## SOUTHERN PACIFIC.

**Southern Pacific Company** operates trains with electricity on the following roads:

1. Visalia Electric Railway, 36 miles of track. See technical description of its 15-cycle electric locomotives.

2. Suburban lines from moles or breakwaters in San Francisco Bay to and in Berkeley, 10 miles; to and in Alameda, 7 miles; in and thru Oakland and Fruitvale to Melrose, 8 miles from the bay; in all about 30 miles of double track, much of which is on city streets. The 1200-volt direct-current, overhead trolley system is used.

The power house is located on the Oakland estuary. It contains twelve 645-h.p. water-tube Parker boilers, fed by fuel oil, one 14-foot by 125-foot unlined steel stack, two Westinghouse double-flow turbo-generators rated 5000 kw. for 1 hour, 7500 kw. for 2 hours, and 10,000 kw. for 1 minute, which supply three-phase, 25-cycle current at 13,000 volts to three substations, each containing six G. E. 750-kw., 600-volt rotary converters, set in pairs, connected permanently in series, and mounted on a common base.

3. Peninsula Railroad between Mayfield, Congress Junction, Saratoga. San Jose, New Meriden Corners, Monta Vista, Los Altos, Mayfield, and Palo Alto, over double track, one of which tracks is used for steam trains. The electric mileage is 40. Elec. Ry. Journ., January 20, 1910, page 204.

4. Pacific Electric Railway, having 600 miles of track, and Los Angeles-Pacific Railway having 260 miles of track. Elec. Ry. Journ., November 26, 1910, page 1079.

5. Los Angeles & Redondo Ry., interurban divisions, 100 miles.

6. Street railways in Ontario, Redlands, San Bernardino, Riverside, San Jose, Fresno, Santa Monica freight road, etc.

**Electrification of the Sierra District, Sacramento Division** has been considered since 1907. The division runs from Reno, Nevada, to Sacramento, California, over the Sierra Nevada Mountains, and has 140 miles of road or 200 miles of track. It has a 7000-foot rise in 83 miles, 1.54 per cent. average grade, and a 2.2 per cent. maximum grade.

Electrification would prevent double-tracking the road and would increase the carrying capacity of a single line of rails. Expert reports were to the effect that the road could be operated with electric power for 62 per cent. of the expense of operation by steam, using water power from the Great Western Power Company. St. Ry. Journ., Dec. 14, 1907, p. 1154.

The specifications issued (see Frank J. Sprague's data to A. I. E. E., Nov., 1907, and July, 1910) call for increased capacity by doubling the speed, viz. to 15 m. p. h. for 2000-ton freight and 30 m. p. h. for 400-ton passenger trains, up 2.2 per cent. grades.

The cost of electrification will be large, but the increased capacity on the grades is expected to justify the outlay. Estimates made on cutting new tunnels and lowering the grade to 1.5 per cent. showed the cost to be from 40 to 50 million and the time required eight years. Electrification is estimated to cost 13 millions and the time required 2 years. Electric haulage would also reduce the non-revenue tonnage 20 per cent.

Mallet compounds are now in service on this grade. These are 2400-h.p., 300-ton, oil-burning locomotives having economical boilers. Steam is used in the engines at long cut-offs, making them very wasteful. See description and tests in Chapter II. Their capacity is 1000 trailing tons at 10 miles per hour up 2.0 per cent. grades and 1855 tons up 1.5 per cent. grades.

Julius Kruttschnitt, Vice-President, stated in 1910, regarding the power problem over the Sierras:

> "Electrification for mountain traffic does not carry the same appeal that it did two years ago. Oil-burning locomotives are solving the problem very satisfactorily. Each Mallet compound locomotive hauls as great a load as two of the consolidation type, burning 10 per cent. less fuel and consuming 50 per cent less water."

**References.**

Power Plant for Alameda Lines, E. R. J., Feb. 4, 1911, p. 196.
Electrification of Sacramento Division, S. R. J., Aug. 31, 1907.
Sprague: A. I. E. E., Nov., 1909; Harriman, E. W., March 16, 1907, page 538.
Grade Reduction to Prevent Electrification: Ry. Age Gazette, Feb. 18, 1910, p. 344.
Locomotive Tests, Ry. Age Gazette, Jan. 14, 1910, p. 91.

## TECHNICAL DATA ON PROPOSED RAILROAD ELECTRIFICATIONS.

### BOSTON & ALBANY.

**Boston & Albany Railroad,** owned by New York Central, in Nov., 1910, filed plans with a Committee appointed by the Massachusetts State Legislature for the electrification of 128 miles of its 4-track road between Boston and South Farmington, Mass., a distance of 21 miles. Its plans embrace the use of the 1200-volt, direct-current, third-rail

system with multiple-unit passenger cars for local trains and electric locomotives for thru trains. The plans embrace electrification for 65 per cent. of all Boston & Albany trains leaving Boston.

Large possibilities for greater net earnings are suggested by a greater traffic to be induced, by reduction of fares, and trains at short intervals. Elec. Ry. Journ., Nov. 19, 26, 1910. See estimates, page 513.

## DELAWARE, LACKAWANNA & WESTERN.

**Delaware, Lackawanna & Western Railroad,** as early as 1899, considered the electrification of its suburban tracks in New Jersey. See A. I. E. E., 1900, Vol. XVII, page 106.

A mountain-grade electrification near Scranton, Pa., received consideration in 1909 and 1910. The proposed electric division runs from Clark's Summit, which is 7 miles north of Scranton, to Lehigh, which is 19 miles south of Scranton, or to Mt. Pocono, 34 miles south of Scranton. Electrification is expected to reduce expenses incident to the use of three steam locomotives per train working on 1.5 per cent. grades.

## ILLINOIS CENTRAL.

**Illinois Central Railroad,** at Chicago, presents one of the greatest terminal electrification problems. The road and terminal are spread along the shore of Lake Michigan, adjoining the residence district, a valuable park, and the principal boulevard. The congestion at the terminal is such that the yards could even be double-decked; the enclosure of the tracks by warehouses might work out to advantage.

City Councils of Chicago have not as yet succeeded in getting the railroad to formulate plans for electrification. Electric traction on suburban trains is held back until electrification of all freight and passenger trains can be included.

Electrification has repeatedly received consideration. Good precedent has shown that the extra investment would be more than offset by increase in traffic, reduction in operating expenses, and low cost of central station power in combined switching, terminal, and suburban service.

The problem involves 25 miles of 8-, 6-, and 4-track route, between Flossmar and Chicago; 35 trains with an average weight of 410 tons, in service simultaneously; 12,300-kw. maximum load; 35 per cent. load factor; and 6500 train-miles daily, 5700 being in suburban traffic. In all:

| | |
|---|---|
| Suburban trains, daily | 400, with 1,000,000 ton-miles. |
| Thru trains, daily | 100, with 500,000 ton-miles. |
| Freight trains, daily | 200, with 2,000,000 ton-miles. |
| Switch trains, daily | 400, with 2,000,000 ton-miles. |

Estimated cost per mile is based on the following: Steel transmission lines, one three-phase circuit, $4000; double three-phase circuit, $6000; conduit transmission lines, $20,000; third rail per mile $6400.

Power can be purchased at the rate of 0.75 cent per kw-hr.

Illinois Central electrification is held to be unjustifiable, even for the suburban traffic. President Harahan submitted the statement below of the results which are estimated to follow if the entire suburban service alone were electrified, compared with present steam operation.

Results of operation of suburban business at Chicago for the fiscal year ending June 30, 1909, under steam:

| | |
|---|---|
| Gross earnings | $1,056,446 |
| Operating expenses (82.9 per cent.) plus taxes | 946,734 |
| Net revenue (steam operation) | $ 109,712 |
| Estimated results under electrification: | |
| Gross earnings | $1,056,446 |
| Operating expenses (66 per cent.) plus taxes | 771,681 |
| Net revenue (electric operation) | 284,765 |
| Net revenue (steam operation) | 109,712 |
| Increase in net earnings | 175,053 |
| Estimate cost of electrification | $8,000,000 |
| Interest and depreciation, 10 per cent | 800,000 |
| Saving in operation under electrification | 175,003 |
| Net deficit under electrical operation | $624,947 |

The statement may be badly warped because the assumption is made that electrification will cost $8,000,000, while other valuable estimates for the same track-mileage are $3,500,000; and the assumption is made that electrification will not increase the gross earnings, *i. e.*, attract traffic and regain lost business. Other roads within a few years after electrification have increased their gross earnings 50 to 90 per cent.

**Chicago terminal electrification,** which embraces 25 steam railroads at Chicago, was merged in 1911 with that of the Illinois Central Railroad.

A terminal electrification commission is now employed by the Chicago Association of Commerce, being paid by all of the steam railroads, to report on the necessity for electrification, the mechanical feasibility, and financial problems of the undertaking.

Horace G. Burt is chief engineer of this Commission. George Gibbs and E. R. Hill, who have worked out electrifications of the New York Central, Long Island, West Jersey, and Philadelphia terminals, have been appointed consulting engineers, with Mr. Hugh Pattison, formerly Superintendent of Construction of the Pennsylvania terminals at New York City, as electrical engineer in direct charge of the work.

The rearrangement of steam tracks, the elimination of thru freight

from the business district, and the much-needed revision of freight yards are being studied by George R. Henderson, consulting engineer.

Actual work on electrification may not begin prior to 1915.

**References on Illinois Central Railroad Electrification.**

Sprague: A. I. E. E., June, 1892.
Wallace: A. S. C. E., Feb. 3, 1897; S. R. J., July, 1899, p. 468.
Suburban cars: S. R. J., July 4, 1903; April 30, 1904.
Practicability of Electrification, E. R. J., Oct. 31, 1908, p. 1290.
Engineering News: Comment on Electrification, Dec. 24, 1908.
Symons: On Electrification, Western Railway Club, Feb. 19, 1908.
Seley: On Electrification, Western Railway Club, Nov., 1909; Ry. Age, Nov. 26, 1909.
Harahan: Reports, R. R. Age, Oct., 1909, p. 812; E. R. J., Oct. 30, 1909.
Cost of Electrification: E. R. J., Oct. 24, 1908, p. 1261.
Evans: Reports to City Council, 1909, on terminal electrification.
Delano: Chicago City Terminals, Ry. Age, Dec. 24, 1909.
Extent of Electrification: E. R. J., Oct. 2, 1909, p. 608.
Objections to Electric Traction: Illinois Central, near end of Chapter III.
Bird: Locomotive Smoke in Chicago, Ry. Age, Feb. 17, 1911, p. 321; E. R. J., Feb. 18, 1911, p. 305.

## CANADIAN PACIFIC.

**Canadian Pacific Railway Company** controls two electric railways:

Aroostock Valley Railroad, Maine, a 12-mile, 1200-volt railway.

Hull, Ottawa, Aylmer Division, 26 miles. See description of locomotives, Elec. Engineer, October 7, 1896.

In Ottawa, the company has completed plans, involving about $1,000,000, for the electrical operation of an underground tunnel road, from a point near the foot of the Rideau Canal to the union station; or for a belt line around the city. Elec. Ry. Journ., August 20, 1910.

Rocky Mountain grades, in the past, have frequently been reduced by doubling the length of the winding track. The grades on many divisions are severe, and only a part of ordinary train loads are hauled; yet each train requires 3 to 4 of the largest locomotives. Operation with such groups is dangerous. Economy with steam power, when so used, is evidently low. Water power is abundant in the mountains, could be utilized to advantage for electrical operation of trains, and would prevent expensive grade reduction.

## BUTTE, ANACONDA & PACIFIC.

**Butte, Anaconda & Pacific Railway,** owned by Anaconda Copper Company, had plans drawn in 1910 for the complete electrification of its steam railroad from Butte to Anaconda, Montana, 26 miles. The two cities are located on hills and a deep valley intervenes. Tracks for

storage, mines, terminals, and branches are extensive and the total mileage for which electrification is considered exceeds 50, of 80 total.

Ruling grades on the main line are 0.85 per cent. for east-bound track and 0.41 per cent. for west-bound, while the ruling and continuous grade is 1.5 per cent. for 6 miles to the Anaconda smelter hill, and 2.5 per cent. for 5 miles to the Butte mines.

Passenger service consists of eight 3-car trains, of from 235 to 275 tons' weight, per day, between the cities.

Freight service consists of twenty 960- to 1050-ton ore and supply trains, between Butte and Anaconda, twenty 2800- to 3500-ton trains down the grades from the mines, and many switching movements.

Cost of service per train-mile, from I. C. C. reports, is $2.63, which is higher than ordinary roads in this district, because of the high cost of labor, and the very wasteful use of coal by locomotives on the up- and down-grade, per ton-mile hauled.

Electrification would give a market for water power, now delivered by the Anaconda Copper Company to Butte and Anaconda for mining purposes, at 100,000 volts and 60 cycles. It would decrease the cost of power per ton-mile, increase the train load, and thus increase the capacity of each mile of track on the grades. About $1,000,000 would be required for electrical equipment.

## OTHER PROPOSED AMERICAN ELECTRIFICATIONS.

**Chicago, Milwaukee and Puget Sound Railroad** has had plans drawn for the utilization of water power to haul its trains over the Bitter Root Mountains, for about 100 miles of track between St. Regis, Montana, and St. Joe, Idaho. It is understood that a series of hydraulic dams would be required on the St. Joe River and on the Missoula River.

**Lake Shore & Michigan Southern Railroad** has proposed to apply electric traction for its line between Buffalo and Cleveland. See "Steam vs. Electric Railway Operation for Trunk Line Traffic," Mayer, to A. S. C. E., November 21, 1906; St. Ry. Journ., December 1, 1906.

**Northern Pacific Railroad** has considered the use of electric power on the Bozeman "hill" and also on the Helena "hill," over the Rocky Mountains. Tests were made in 1908 on locomotive requirements, and data and estimates prepared on electrification. Traffic is not too light for commercial practicability, and the load factor will be sufficiently high if the electrification covers 100 miles of route.

**Oregon Short Line** has considered plans for electrification from Salt Lake City over the mountain grades to Pocatella, 171 miles.

**Norfolk & Western Railway** has planned to increase its economy and capacity by the electrification of the mountain grades near Bluefield, W. Va.

Many American railroads are now studying plans for electrification.

## EUROPEAN ELECTRIC RAILROADS.

### ENGLAND.

In Great Britain there are about 237 miles of steam railroad track operated solely by electricity and in addition 200 miles operated partly by electricity, 87 electric locomotives and 821 motor cars, in addition to the underground tubes, and the two old steam "Circle" lines, now worked electrically. There are five provincial railroads which employ electric traction for train service: Mersey, North-Eastern, Lancashire & Yorkshire, Midland, and London, Brighton & South Coast. The last two are single-phase roads. Maps: St. Ry. Journ., October 4, 1902.

**Mersey Tunnel Railway,** between Liverpool and Birkenhead, formerly a steam road, was electrified in 1903. It now has 5 miles of route and 10 miles of track. The road extends thru a tunnel under the Mersey River. The reason for electrification was to overcome the difficulties due to grades and the ventilation in the tunnel, and to regain traffic which had been taken in competition.

The service with steam operation consisted normally of 7 coaches per train, while with electric service there is a 3-minute headway on the main line and 6 minutes on the branches. Steam trains formerly weighed 154 tons, where electric trains now weigh 137 tons. Formerly there were 12 steam trains per hour, now there are 20 electric trains per hour. Steam locomotives formerly used were 18, which handled 96 coaches, with a total of 4280 seats. Electric motor cars are now 24, which haul 33 coaches, with a total of about 3156 seats. The train-miles per hour are now 50 per cent. greater than in the heaviest steam service. Motor cars are 60 feet long, have four 100-h. p. motors.

Power station has three 1250-kilowatt, d.-c. units and a battery.

Mersey Railway was the first road to show clearly, from operation, that there was no theory about the increased net earnings with electric traction as compared with steam, as the following table shows:

Passenger traffic increased 120 per cent.; receipts 85 per cent.

Electric working reduced from .20 to .17 cent per ton-mile.

Coal cost reduced from $4 to $2.10 per ton.

Average speed with stops increased from 15.6 to 19.9 m. p. h.

Maintenance of way reduced from 0.42 to 0.18 cent per ton-mile.

Life of rails increased 47 per cent. per ton average rolling load.

Ton-miles per annum increased from 43,000,000 to 67,000,000.

Total cost of working and maintaining the locomotive and engineering department reduced from 0.46 to 0.30 cent per ton-mile.

Total cost of operation including general charges but excluding interest on additional capital for electrification reduced from .68 cent to .48 cent per ton-mile.

Total cost of operation including general charges, and including interest on additional capital for electrification have been reduced from .68 cent to .58 cent per ton-mile.

J. Shaw: British Institution of Civil Engineers, Nov., 1909. Kirker: Electric Journal, May, 1906; Electrical Age, Jan., 1910; S. R. J., Apr., 4 1903.

**North-Eastern Railway,** formerly a steam road, electrified in 1904, comprises two miles of four track, and 35 miles of double track, or 82 miles of single track near Newcastle upon Tyne. Stations are $1\frac{1}{4}$ miles apart. The 600-volt, direct-current, third-rail system is used. There are 62 motor cars of 250 h. p., and 44 trail coaches, and 6 freight locomotives.

"A much greater amount of work is now done at the terminal stations as there are no engines to attach or detach; the signal operations are reduced about one-half accelerations realized decreased running between stations from 15 per cent. to 19 per cent. It would have been impossible to carry by the steam service the number of passengers that now are electrically conveyed." Dr. C. A. Harrison to British Institution of Civil Engineers, November, 1909. S. R. T., June 20, 1903.

**Lancashire & Yorkshire Railway,** electrified in 1904, between Liverpool and Southport, England, has a route length of 40 miles, but 82 single-track miles. In 1910, a belt line between the two cities via Ormskirk was added.

Service is provided with 80 motor cars and 52 coaches, weighing 51 and 23 tons respectively. Four-car 1200-h.p. trains are usual. The direct-current, 600 volt, third-rail system is used.

E. R. J., Jan. 30, April 2, 1904; Aug. 4, 1906; Aspinwall, Inst. of M. E., 1909.

**Midland Railway** in 1908 electrified its double-track steam line between Heysham, Morecambe, and Lancaster, 23 miles of track. The 6600-volt, 25-cycle, single-phase system is used. There are now three 43-ton, 60-foot, 72-passenger motor cars and six 21-ton coaches. Power is produced by gas engines having a rated capacity of 450 kilowatts.

The Electrician, June 12, 19, 26, 1908; July 4, 1908.

### LONDON, BRIGHTON & SOUTH COAST.

**London, Brighton & South Coast Railway,** the oldest steam road in England, built in 1841, began the use of electric traction in 1909 on its South London 9-mile division, and in 1911 on its Crystal Palace 14-mile division, there being altogether 62 miles of single track in operation.

Electrification was decided upon as advantageous not only for the conditions on the suburban division, but also for the 50-mile route from London to Brighton, between which points there are about 40 trains each way per day. The directors have decided to electrify the entire 480 miles of track prior to 1916. The 25-cycle, 6700-volt, single-phase system was chosen for the work.

Motor-car trains are operated. Service is furnished by 46 motor cars and 68 coaches. of which 16 motor cars have four 115-h. p. and 30 have four 175-h. p. motors. Motor cars weigh 55 tons and 60 tons respectively, and haul two 35-ton coaches. Seats per car are about 67. Distance between stops is about 4300 feet, stops are 20 seconds, and schedule speed 22 m. p. h. Motors are A. E. G., single-phase, compensated repulsion type. Voltage is 750; air gap is 3 mm.; gear ratio is 4.24, and acceleration rate is 1.0 m. p. h. p. s. Commutators run 50,000 miles between turnings. Motor efficiency is over 80 per cent., power factor of the system is 80 per cent., and energy consumption at the power station is 65 to 75 watt hours per ton-mile with the above stops, and 34.4 on non-stop, 37-m. p. h. schedule trips. Each motor car averages 58,000 miles per annum.

Contact line is the double catenary, V type. Line insulators were tested mechanically to 14 tons, and electrically to 65,000 volts. Many low bridges and tortuous routes exist near terminals. Collectors are aluminum bows, contactors have a groove for grease; pressure is 10 pounds; life is 4500 miles; and cost of renewals is 10 cents per 1000 miles.

The results of operation for the first six months of 1910 show that the passenger traffic increased from 2,000,000 to 3,750,000, and the daily train mileage from 687 to 1465. Part of the increase was enticed away from the tramways, part was new business induced by a reduction of fares, which reduction became possible by reason of economies effected by electrical operation, so that the entire gain can be stated to be due to the adoption of electricity.

**References.**

E. R. J., Dec. 30, 1905; March 6, 1909; April 1, 1911, p. 582.

Dawson's "Electric Traction on Railways," 1909.

Dawson: London Electrician, Sept. 9, 1910; Extension to Crystal Palace, B. I. C. E., March, 1911.

### SWEDEN AND NORWAY.

**In Sweden** the State Railway has been experimenting since 1905, near Stockholm, with single-phase, 25-cycle electric locomotives, also 18,000 to 25,000-volt contact lines. The locomotives have been described. The work has now passed the experimental stage.

In 1911 the State began the electrification of the steam railroad between Kiruna and Riksgransen, 93 miles apart. Thirteen 2000-h.p. freight, and two 1000-h. p. passenger locomotives were ordered from Siemens. A change was made to the 15-cycle, single-phase, 15,000-volt system. The service calls for the haulage of ore, near the Norwegian frontier, in 2,200-ton trains with 2000-h. p. locomotives; and the haulage

of passenger and express trains with 1000-h. p., 62-m. p. h. locomotives. The grade is a steady encline of one per cent. A 36,000-kv-a., single-phase water power station has been built at Porjus Falls, from which power is transmitted at 80,000 volts. The estimated cost of the complete undertaking was $4,000,000.

**In Norway** electrification of railways is proceeding on a smaller scale. Motor-car and locomotive-hauled trains are being operated between Thamshavn and Lokken, an 18-mile road; also on the Rjukan Railway (Notodden-Tinoset and Vestfjorddals Railway), 29 miles.

**References on Electric Railways in Sweden and Norway.**

Swedish State: S. R. J., Apr. 15, 1905, March 31, 1906; E. W., Nov. 11, 1905. Single-phase Locomotive Installations, and Cost of Electrification, E. R. J., Oct. 15, 1910, p. 857; May 6, 1911, p. 788.

Thamshavn-Lokken: Ry. Age., Sept. 2, 1910.

## FRANCE.

The railways of France, in geographical order are: The Northern, Eastern, Paris-Lyons-Mediterranean, Southern, Paris-Orleans, and the Western. Paris-Lyons-Mediterranean extends from Paris to Marseilles; Paris-Orleans extends from Paris thru Orleans and on to the south to Tolouse where it joins the Southern; Western extends from Paris to points on the English channel, and Southern extends across Southern France, parallel with the Pyrennes Mountains, from the Atlantic to the Mediterranean. Western and Southern are under government control.

**Paris-Lyons-Mediterranean,** in 1900, electrified 40 miles of track near its Paris terminal, and uses the direct-current 600-volt third-rail system. Plans for electrification between Gap and Barcelonette have been adopted. Reference on its Fayet-Chamonix road to Mt. Blanc: St. Ry. Journ., Feb. 7, 1903.

**Paris-Orleans Railroad,** in 1900, electrified 46 miles of track, using the direct-current, 600-volt, third-rail system on the Paris-Juvisy, 14-mile section. About 200 thru trains are hauled daily, by 11 electric locomotives, and about 100 suburban trains are hauled by motor cars. The original power plant at Ivry had three 1000-kilowatt, three-phase, 25-cycle, 5500-volt generating units which fed three substations.

**Western of France Railroad** has used electric traction since 1901, on the Paris-Versailles, 11-mile suburban division. Plans have been adopted for two important 20-mile extensions, to Argenteuix and to St. Germain, the cost of which is estimated at $13,400,000. Other electrification plans, if carried out, will involve an expenditure of $60,000,000.

**Midi (or Southern)** Railroad of France began to equip its steam line

for electric traction in 1909. The first work was on the 65-mile section lying between Pau and Montrejean. One of the heavy grades is 3.5 per cent. for 7 miles. It is intended later to equip the 200 miles between Tolouse and Bayonne. The single-phase, 17-cycle system is used.

Six 89-ton, 1200-h. p. freight locomotives have been purchased from Westinghouse, and one 94-ton, 1600-h. p., locomotive from the Allgemeine Elektricitäts Gesellschaft. See description, page 385.

Motor cars haul 115-ton passenger trains on the branch lines at 38 m. p. h. Thirty 50-seat, 62-ton motor cars are used, each equipped with four 285-volt, 125-h. p. single-phase motors.

Four water-power plants, at Egat, Soulom, Porta, and Ossau, with a total rating of 38,000 kilowatts, will be used. Energy will be transmitted at 60,000 volts to five substations where it will be reduced by step-down transformers to 12,000 volts for the contact line.

**References.**

Elec. Ry. Journ., Oct. 15, 1910; June 3, 1911, p. 962.

### SPAIN.

**Santa Fe-Gergal Railway** of Spain started the electrification of its main line from Linaries to Almeria, in southwestern Spain, in 1907. The mileage electrified to 1909 is 15. The equipment consists of five 320-h. p., 30-ton locomotives designed by Brown, Boveri & Company.

The service consists of the haulage of light passenger trains with a single locomotive, and freight trains which weigh from 150 to 300 tons with two locomotives.

The system used is the three-phase, 15-cycle, 5,500-volt, double-trolley, without separate transmission lines and substations.

### HOLLAND.

**Rotterdam-Hague-Scheveningen Railway** of Holland, opened in October, 1908, is a good example of a 10,000-volt, 25-cycle, single-phase road. Route length is 22 miles; mileage is 48.

Generator capacity installed is 5700 kv-a. Four 600-kv-a. and four 1200-kv-a. step-down transformers are used, with three-phase, two-phase line connections. Trolley construction comprises a catenary, and a 4/0 contact wire.

Rolling stock consists of twenty 61-foot, 56-ton, 3-axle motor cars, and nine 34-ton trailer cars. Each motor car has two single-phase compensated, series, 180-h. p. Siemens-Schuckert motors, geared for 60 m. p. h. The controller delivers 133 to 338 volts to the motor.

Train service in winter consists of 52 trains per 16-hour day, which

average 235 miles per motor car; in summer, of 160 trains, which average 357 miles per motor car. Three-car trains are in common use.

**References.**

Ry. Age, July 8, 1910; St. Ry. Journ., Oct. 2, 1909.

**GERMANY.**

About 94 per cent. of all railroads in Germany are state railroads The single-phase, 15-cycle, 10,000-volt system was adopted in 1908 by the Prussian State Government. The development and extent of electrification in Germany are shown below:

ELECTRIC RAILROADS IN GERMANY.

| Name of railroad. | Single-phase. | | Mileage. | Motor-cars. | Locomotives. | Year built. |
|---|---|---|---|---|---|---|
| | Cycles. | Volts. | | | | |
| Prussian State: | | | | | | |
| Spindlersfeld | 25 | 6,600 | 3 | 4 | 0 | 1903 |
| Oranienburg | 25 | 6,600 | 1 | 0 | 3 | 1906 |
| Blankanese-Ohlsdorf | 25 | 6,600 | 17 | 110 | 0 | 1907 |
| Altoona Harbor | 25 | 1,500 | 2 | 0 | 1 | 1910 |
| Magdeburg-Leipzig- | 15 | 10,000 | 23 | 2 | 7 | 1910 |
| Berlin City, Circle | ........ | ........ | 250 | ........ | ........ | Project. |
| Berlin-Grosslichterfelde. | D. c. | 550 | 12 | 24 | 0 | 1903 |
| Neiderschoenweide-Koepenick. | 15 | 640 | 4 | 0 | 1 | 1905 |
| Bavarian State: | | | | | | |
| Murnau-Oberammergau | 15 | 5,500 | 15 | 4 | 2 | 1905 |
| Salzburg-Berchtesgaden | 15 | 10,000 | 30 | ........ | ........ | 1911 |
| Karlsruhe-Herrenalb | 25 | 8,000 | 34 | 7 | 4 | 1909 |
| Baden State: | | | | | | |
| Wiesental Ry. or Basel-Schopfheim-Zell. | 15 | 10,000 | 37 | 15 | 12 | 1909 |
| Rhine Shore Ry.: | | | | | | |
| Cologne-Bonn | D. c. | 990 | 30 | 10 | 0 | 1908 |
| Cologne-Treves | ........ | ........ | 112 | ........ | ........ | Project. |

**References on Electric Railroads in Germany.**

Berlin-Zossen high-speed tests of 1901; S. R. J., Sept. 9, Oct. 28, 1905.

Berlin Elevated & Underground: Engr. Mag., Vol. 27, p. 731, 1904; St. Ry. Rev., April and Oct., 1902; Ry. Age, Sept. 23, 1910.

Eifel Bahn Ry.: Cologne to Treves, 112 miles, S. R. J., Oct. 12, 1907.

Electrification of Geneva Railroads: Electrical Review, March 6, 1909, p. 434.

Weisental Ry.: E. R. J., Dec. 11, 1907, p. 1177.

Peters: Development of German Railways, Ry. Age, Dec. 16, 1910.

See references under Systems; and under Technical Descriptions of Locomotives.

ELECTRIC RAILWAYS IN AUSTRIA.

| Name of railway. | Electric system. | Motor cars. | Loco-motives. | Route miles. | Mile-age. | Year open. |
|---|---|---|---|---|---|---|
| Tabor-Bechyn | D. c., 3-wire, 1500-volt | 2 | 0 | 15 | 16 | 1903 |
| Innsbruck-Fulpmes | 1-phase | | | 12 | ...... | 1904 |
| Bludenz-Schruns | D. c., 2-wire, 500-volt | | | 8 | ...... | 1905 |
| Vienna-Baden | 1-phase, 15-cycle, 10,000-volt | 20 | 2 | 18 | 41 | 1907 |
| Haute Vienne | 1-phase, 25-cycle, 10,000-volt | 35 | 0 | ...... | ...... | 1910 |
| Trient-Male | D. c., 800 volts | | | 37 | 50 | 1909 |
| Neumarkt-Waizenkircken | D. c., 500 volts | | | 10 | ...... | 1908 |
| Waitzen-Budapest-Godolla | 1-phase, 15-cycle, 10,000-volt | 11 | 4 | 31 | 36 | 1910 |
| St. Polten-Mariazell | 1-phase, 25-cycle, 6000–volt | 0 | 23 | 56 | 68 | 1910 |
| Mittenwald: Munich-Innsbruck. | 1-phase, 15-cycle, 10,000-volt | | 6 | 63 | 69 | 1910 |
| Vienna-Pressburg | 1-phase, 15-cycle, 10,000-volt | | 11 | 42 | ...... | 1911 |

## SWITZERLAND.

**Swiss Federal Railways** on December 31, 1909, owned 1825 miles of railway, leaving 973 miles outstanding in the hands of private companies.

Experimental work, between 1904 and 1906, on the short Seebach-Wettingen branch, with Oerlikon and Siemens locomotive hauled trains, proved that 15 cycles, 15,000 volts, catenary construction, single-phase commutators, and side-rod locomotives were practical for heavy railways.

Simplon Tunnel road, Burgdorf-Thun interurban, and 21 meter-gage roads, operated by the Confederation, use electric traction. Plans have been developed to use electric traction on all roads. See report of Commission on Electrification, St. Ry. Journ., Nov. 10, 1906, p. 950. See technical description of Simplon tunnel locomotives.

**Burgdorf-Thun Railway** was the first meter-gage, electric interurban road in Switzerland operated under steam railroad conditions. The road is 25.4 miles long. It was placed in service in July, 1899.

Power comes from a 4500-kilowatt water power plant at Spiez, as three-phase current, at 15,500 volts. Fourteen transformer stations, with a maximum capacity of 450 kilowatts each, which corresponds to the load of a double train, are used to reduce the pressure from 15,000 to 750 volts alternating for the two-wire, three-phase contact line. Trolley line consists of two hard-drawn, 8-mm. wires, 15.9 to 17.0 feet above the rails.

Rolling stock consists of six 32-ton motor cars with four 55-h. p. motors, and 10 passenger coaches. Speed is 22 m. p. h.

Two 100-ton, 300-h. p. electric locomotives used for the freight traffic run at 11 and at 22 m. p. h. and each has a capacity for hauling 100 tons at 11 m. p. h. on a 2.5 per cent. grade, or 50 tons at 22 m. p. h. on the same grade. The locomotive rotor runs at 300 r. p. m.,

and is geared to 2 sets of gears connected to a countershaft, which drives the 2 axles of the locomotive by means of a side-rod.

**References.**

Motor equipment, drawings: S. R. J., Dec. 30, 1899; June 7, 1902.

**Bernes Alps Railroad,** connecting Berne, Spiez, Frutigen, in Switzerland, and the Simplon Tunnel in Italy, completed a standard gage over and thru the Alps, in 1911. Its Lotschberg double-track tunnel, which adjoins the Simplon tunnel, is 8 1/2 miles long, of large cross-section, 19.8 by 26.4 feet, for double track. The tunnel will cost $7,500,000 and the entire railroad, which is 52 miles long, $15,000,000.

Oerlikon, A. E. G., and Siemens locomotives were described.

Motor cars are 65-foot, 62-ton, and seat 64 passengers. Each hauls trailers in 177 trains up long 2.7 per cent. grades at 28 m.p.h.

The system used is the 15-cycle, 15,000-volt, single-phase.

**References.**

Electrical Review, March 6, 1909; E. R. J., June 18, 1910, Oct. 29, 1910.

## ITALY.

**Italian State Railways** have been electrified as follows:

**Milan-Varese-Porto Ceresio Railroad** in 1901, for local and suburban service. There are 48 miles of first-class road and 81 miles of track. Stops average 2.9 miles apart. It is operated by the Mediterranean Railway Company.

The direct-current, 660-volt, third-rail system is used. Trains contain three 45-ton motor cars, each with four 160-h. p. motors, and three 35-ton coaches. Electric locomotives are used for freight. Grades are heavy. Tariffs were reduced 50 per cent. after electric power was adopted, yet the earnings increased 25 per cent. Electrification cost was only $12,000 per mile.

**Valtellina Railway,** or Rete Adriatica, in 1902. This is an electrified steam road, with light traffic, between Lecco on the south and Chiavenna, 41 miles north, with a branch to Sondrio, 25 miles west, in all 66 miles of road and 70 miles of track. The road was extended south from Lecco to Milan, a distance of 25 miles, in 1911.

The three-phase, 15-cycle, 3000-volt system is used.

Locomotives and service are described in Chapter IX.

**Giovi Railway,** between Genoa, Pontedecimo, and Bussala, which electrified 13 miles of double track in 1909. This is a three-phase mountain-grade freight road using 30 Westinghouse locomotives.

**Savona-San Giuseppe,** a 13-mile, three-phase, 15-cycle, 3000-volt freight road in northern Italy, in 1909.

**Domodossola-Iselle,** an extension south from the Simplon Tunnel, about 10 miles of track, in 1910.

**Bardonnechia-Modana,** including the Mont Cenis tunnel railway, between Modane and Turin, completed for the Turin Exposition in 1911. Three-phase, 7000-volt, 2000-h. p., Brown-Boveri locomotives are used.

**Neapel-Salerno** and **Torre Annumziata-Castellamare** roads.

**Turin-Pinerollo-Torre-Pelice Railway,** a branch line southwest from Turin, on which Mr. Verola, the chief engineer of the electrical department, states the single-phase system is necessary because variable speeds, up to 50 m. p. h., are required for light passenger trains.

**Gallarate-Arona,** and **Gallarate-Laveno,** third-rail lines.

### References on Italian State Railways.

Milan-Varese-Porto Ceresio: S. R. J., Aug. 3, 1901; Dec. 6, 1902; May 13, 1905.
Hammer: General notes, A. I. E. E., Feb., 1901; S. R. J., May 2, 1903, p. 663.
Waterman: Descriptive, A. I. E. E., June, 1905.
Valtellina Railway: S. R. J., March 16, 1901; May 30, 1903.
Stillwell: A. I. E. E., Jan., 1907; S. R. J., April 6, 1907, p. 575.
Valatin: S. R. J., Descriptive, Aug. 5, 1905; Jan. 4, 1908.
Cserhati: Operation results, S. R. J., Aug. 26, 1905.
Wilson & Lydall: Power Curves, in "Electrical Traction," Vol. II, p. 113.
Electrification of 193 miles: S. R. J., May 11, 1907.

## CONCLUSIONS AND SUMMARY.

The technical descriptions, statistical tables, and summary of work done in Electric Traction for Railway Trains are so rich in suggestive details that they will repay a careful study of the development and the present status. What the next decade will show may be surmised.

European development is now and always will be limited to short-haul work, but the American development for long-distance, trunk-line work is most attractive. Where it has been on a large scale, for freight, switching and passenger service, the work done has justified the undertaking; as the size of the project increases, the economic gain increases, and in transportation this is of vital importance. Capital has been spent for electric traction on the faith that it was wisely spent, to attract traffic and to operate trains economically.

# INDEX.

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